May 2001

Dear Deep Trek Workshop Participant:

The National Energy Technology Laboratory (NETL) and the Sandia National Laboratories are pleased to provide the proceedings of the Deep Trek Workshop held on March 20-21, 2001 in Houston. These proceedings include the presentations made during the workshop and the breakout session results that were developed for advanced smart drilling systems, drilling and completion fluids, completion based well design, and drilling diagnostics and sensor systems. A list of participants is also included. We have attempted to accurately capture all the ideas, comments, and consensus opinions generated during the workshop. If you note any omissions or wish to provide additional information, we welcome your comments.

We hope your organization is interested in a new deep trek initiative that can result in collaborative efforts to develop the technologies necessary to reduce drilling costs and enhance the economics of deep hydrocarbon resources. With this in mind, NETL is already taking steps to analyze the workshop results and formulate a solicitation for immediate release should funds become available for this activity. Further details and updates will be available at the NETL website: www.netl.doe.gov. We hope that all stakeholder groups will use these proceedings in their planning endeavors as well.

Your active participation in the workshop and the breakout work sessions is sincerely appreciated. Over 95 participants from more than 50 organizations representing various stakeholders groups provided a wealth of information and opinions. This collaboration among stakeholders groups will undoubtedly accelerate the planning for advances in deep drilling technologies.

We look forward to your future participation in Deep Trek.

Sincerely,

Brad Tomer,
Product Manager
Gas Exploration, Production, and Storage
Strategic Center for Natural Gas

DEEP TREK WORKSHOP

EXECUTIVE SUMMARY

The National Energy Technology Laboratory (NETL) and the Sandia National Laboratories hosted the Deep Trek Workshop on March 20-21, 2001. The purpose was to gather stakeholder input on the technology gaps and needs in the area of drilling and completing deep oil and gas wells and how the DOE can collaborate with industry to meet these needs. Specific technology challenges and opportunities focused on drilling and completion fluids, completion-based well design, advanced smart drilling systems, and drilling diagnostics and sensor systems. These workshop proceedings include all of the speaker presentations and two appendices for the breakout session products and the participant list. The proceedings are publicly available at he NETL website: www.netl.doe.gov, where CD-ROM ordering is also available.

During the workshop, 96 participants from 53 organizations actively shared ideas through presentations and facilitated breakout sessions. In addition, the industry presenters gave detailed lists of their drilling needs for an R&D program. In the breakout sessions, structured brainstorming and critical analysis were used to identify barriers and technology opportunities and to prioritize collaborative actions. The workshop is expected to enhance dialog with industry on how to develop strategic alliances among industry, academia, and government.

BACKGROUND

The limits of conventional well construction technology are tested in drilling and completing deep wells. The rock is typically hot, hard, abrasive, and highly pressured. The produced fluids are, in many cases, corrosive. Control of well bore trajectory and placement of casing and cement are difficult problems. Today, it is tremendously expensive to drill at depths greater than 16,000 feet. For example, as much as 50% of drilling cost can be encountered in the last 10% of the hole length in deep wells. It is not uncommon to encounter a penetration rate of only two to four feet per hour at an operating cost of tens of thousands of dollars a day for a land rig. It costs millions of dollars a day if this low penetration rate is encountered on an offshore location. In deep formations the driller spends significantly less time on a percentage basis "making hole" than in shallower wells. Some ways to keep a driller "making hole" include: reduce the number of "trips" out of the hole, increase bit and drilling assembly life, reduce corrosion/erosion effects, and increase the driller's knowledge of what is happening downhole in real time. In addition, the costs and problems of deep drilling get worse because drilling rigs have a limit on the maximum depth, according to the weight, at which they are designed to operate. Since deeper holes require longer drillstring and casing and thus more weight, there are only a limited number of rigs available to drill deep wells.

PROGRAM GOALS

The Deep Trek initiative is designed to develop technologies that make it economically feasible to produce deep oil and gas resources. Deep Trek will focus on increasing the overall effective rate of penetration (ROP) for deep drilling. This work will include high performance "smart" systems and materials for deep, harsh environments. Smart systems will include advanced sensors capable of high temperature, high pressure operation to enable logging while drilling and measurement while drilling systems to operate. These systems will allow the driller to anticipate problems and significantly reduce the need to pull the drill string. New systems will be developed to allow the data to be transmitted to the surface in real time. High-speed data transmission is a difficult venture in the drilling environment and is much more problematic in high temperature, high pressure conditions. Advanced materials development will be aimed at reducing weight, increasing resistance to corrosion/erosion, and integrating the data transmission system. One of the goals of this work is to develop lighter, erosion resistant drilling and casing strings, which would extend the depth capabilities of the existing rig fleet rather than requiring that new rigs be fabricated. Individual components will be developed first and then demonstrated together in a deep drilling system. Perhaps the greatest need is to view the well construction process from a total systems perspective and to incorporate new information technology in the process.

PUBLIC BENEFIT

In the recent National Petroleum Council gas study, one of the leading frontiers for gas resource development is in deep formations. Per EIA estimates, 7% of U.S. gas production in1999 came from deep formations; this is expected to increase to 14% by 2010. Without additional improvements in drilling technology, this deep gas resource will be developed primarily as a result of increased gas price. The situation is aggravated by the high and escalating costs associated with deep drilling. There is currently no technology based "light at the end of the tunnel" to give hope for a future solution.

Because lower gas prices will be essential for economic growth, the investment in deep drilling technology now is expected to have an order of magnitude payoff in future economic benefit. Pressure for this benefit is seen with the increasing demand for gas while supply costs are also escalating. Future gas demand increases are also expected because it is the "fuel of choice" for environmental impact mitigation associated with electric power generation. Current gas demand estimates could prove conservative should additional environmental legislation be enacted based on international agreements such as those currently being considered.

WORKSHOP BREAKOUT SESSIONS

Five parallel breakout sessions were held on the afternoon of Tuesday, March 20 and the morning of Wednesday, March 21:

- Advanced Smart Drilling Systems – Group A
- Advanced Smart Drilling Systems – Group B
- Drilling Diagnostics & Sensor Systems
- Drilling & Completion Fluids
- Completion-Based Well Design

The scope definitions for these technical areas were bounded by the following target goals (temperature aspects were noted in some of the groups):

- Greater than 16,000 feet
- U.S. onshore
- Gas & oil

- Next 5-year action plan
- Drilling completion & stimulation (DCS)

Through the breakout group sessions, participants identified:

- Key barriers and issues to meeting Deep Trek,
- Technical opportunities to overcome these barriers, and
- Action plans identifying objectives, actions and products, resources and timeframe, and collaboration opportunities.

A short summary is provided below for each technical area and its top priority opportunity action plan. Actual "storyboard" products for barriers and issues, opportunities, and action plans are in Appendix A. Although only the top opportunities were scrutinized in detail, many other important opportunities were noted for consideration. Each breakout group presented its results in a concluding plenary session, but these presentations are not included due to the repetition. Participants are listed in Appendix B.

RESULTS

Advanced Smart Drilling Systems – Group A

Two of the highest priority opportunities were real time data transfer and real time data instrumentation. Their action plans were identical and began with formation of a committee of government and industry personnel to spearhead the plan followed by studying the state of the art and previous accomplishments in this area. The next steps included defining the problem and goals, performing a gap analysis, re-evaluating the economics of existing technologies, and considering the end user needs. Additionally, determination of the value-added is necessary along with identification of potential solutions followed by request for proposals (RFPs). Industry should define the problem while government should hold workshops for data collection. An equal partnership of government and industry is needed with additional assistance from universities. The government was identified as having connections for team formation.

Advanced Smart Drilling Systems – Group B

The highest ranked priority for this advanced smart drilling group was to develop a rig operator decision support system with an open architecture that is applicable to all wells. Four tasks are needed: develop higher data rate telemetry systems, form consortium to define standards for open architecture information standards, develop logic algorithms for drilling applications that fuse real time downhole and surface data, and upgrade temperature and pressure performance for sensors and electronics while looking for other markets to support. All of these tasks will involve some sort of industry and government or vice versa collaboration.

Drilling Diagnostics & Sensor Systems

The highest ranked opportunity for drilling diagnostics and sensor systems was downhole diagnostics drilling parameters including data validation, weight torque on bit, and state of bore hole analysis. Actions focused on developing a low cost, reliable, high accurate, and retrievable tool while preventing bit damage. Resources needed include better seismic while drilling, downhole processors, and better materials. Lead roles focus on service companies via JIPs with lab and university research development. Leveraging of funds will be essential.

Drilling & Completion Fluids

In order to optimize the fluid performance, the industry needs economic tests and simulators developed so that they can determine drill fluid contribution to well-bore stability. This would also help them evaluate the mechanical/chemical interaction of rock/fluid. This could be accomplished through a collaborative effort with industry, the government, and universities. Actions taken to reach a solution include defining the problem, developing a fundamental understanding of the mechanisms, defining the constraints, developing test procedures and equipment, and field validation.

Completion-Based Well Design

The highest ranked priority for completion-based well design was the development and application of high-temperature, high-pressure sensors and information tools for drilling and completion processes. Field tests of sensors, data delivery systems, and data collection and analysis systems are necessary. For example, current management while drilling (MWD) needs to be robust. Expertise needs include high-temperature and high-pressure electronics, micro devices, data transmission, and information technology. A neutral but inclusive JIP consortium should lead this effort with service company involvement and a clear path to commercialization. There should be balance cost shared funding across all critical pieces.

This group also repeatedly noted a number of general issues and crosscutting topics. There is a growing concern over the continued availability of the necessary technical expertise to apply advanced technology. What may be termed the expertise pipeline for new talent, as measured by university programs and the flow of students, continues to shrink. There is also a general industry tendency to focus more on the short-term benefits in reducing up-front costs of drilling as opposed to maximizing the longer-term payoff of longer well life and greater total production from improved completion tools and techniques. In a generally risk-adverse environment, it is difficult to promote the use of new technology in field operations. The cost of failure is prohibitive, particularly in very costly deep wells. Another group mentioned technology test underwriting, performance pricing, and exportabilty in their report out.

NEXT STEPS

NETL is already taking steps to analyze the workshop results and formulate a solicitation for immediate release should funds become available for this activity. Further details and updates will be available at the aforementioned NETL website.

DEEP TREK WORKSHOP

CONTENTS

I. Presentations

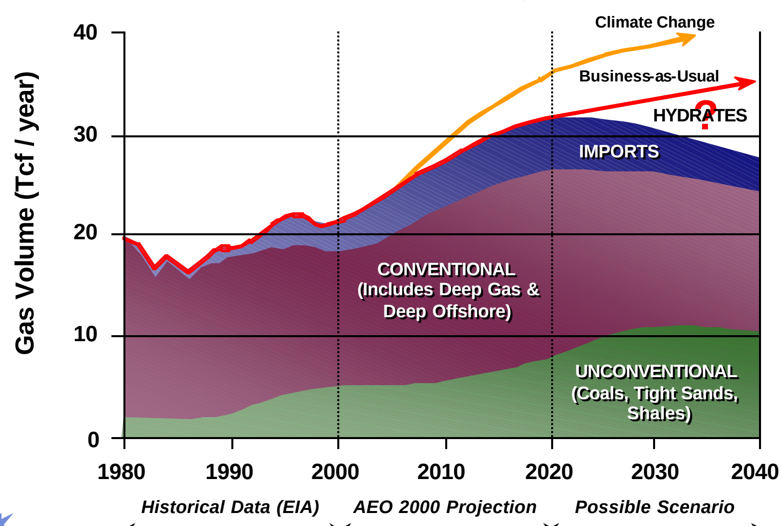
A. GAS EXPLORATION, PRODUCTION, AND STORAGE

Brad Tomer
National Energy Technology Laboratory, U.S. DOE

Gas Exploration, Production, and Storage

Strategic Center for Natural Gas

Enough Affordable Natural Gas to Meet Demand?

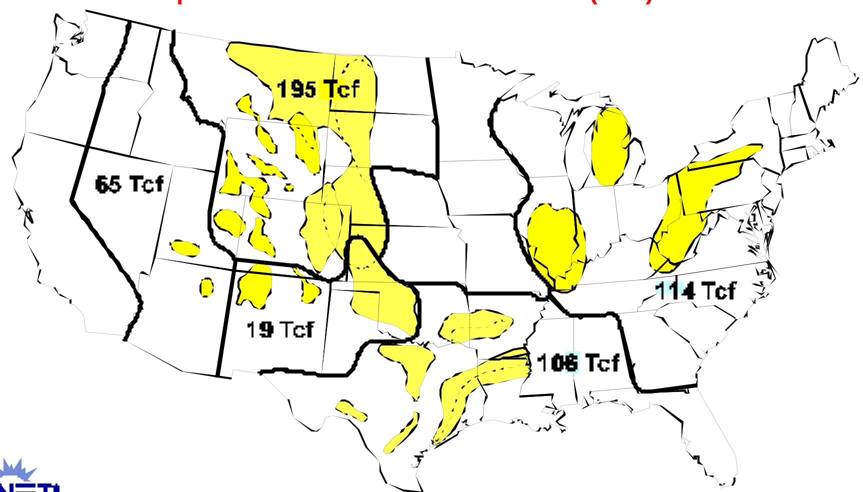


Strategic Center for Natural Gas

Key Issue
Development of Federal Lands

- 460 Tcf in low perm formations

- 285 Tcf (60%) is on federal lands



Strategic Center for Natural Gas

Gas Exploration & Production Program Goals

- **Near-Term: Recover more from developed fields**
  - Locate by-passed zones in conventional reservoirs
  - Enhance stripper well production
- **Mid-Term: Exploit low-permeability formations**
  - Reduce drilling cost
  - Improve success rates in finding gas
  - Increase recovery efficiency
- **Long-Term: Encourage E&P of frontier resources**
  - Deep (>16,000 feet) gas
  - Methane Hydrates
  - Offshore gas

Strategic Center for Natural Gas

Partnership Approach

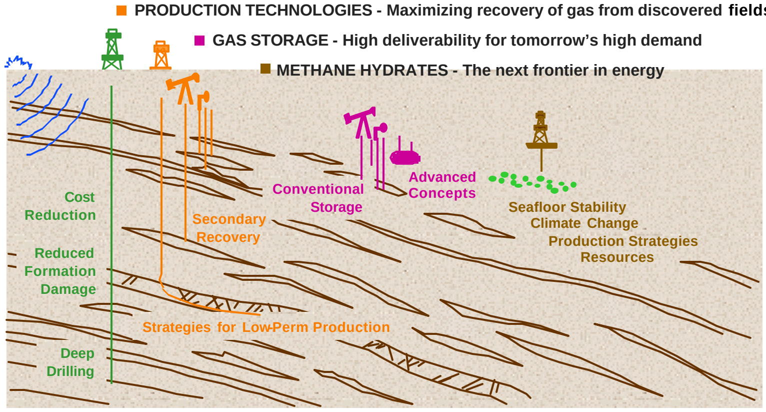
- **R&D conducted with various partners**
  - Industry (Maurer, Union Pacific Resources, Burlington)
  - Other federal agencies (USGS, Energy Efficiency)
  - National labs, universities and industry associations
- **Cost shared projects are common**
  - Field tests (independent producers)
  - Development of technologies (service companies)
- **Technology transfer**
  - Cooperative agreements with commercializing partner
  - Successful field demonstrations
  - Petroleum Technology Transfer Council

NETL

Strategic Center for Natural Gas

Gas Exploration, Production, and Storage

- RESOURCE ASSESSMENTS - Quantifying the nature and potential of gas resources
- EXPLORATION TECHNOLOGIES - Enabling effective natural fracture detection
- DRILLING, COMPLETION, & STIMULATION - Reducing the costs and risks of extracting natural gas
- PRODUCTION TECHNOLOGIES - Maximizing recovery of gas from discovered fields
- GAS STORAGE - High deliverability for tomorrow's high demand
- METHANE HYDRATES - The next frontier in energy



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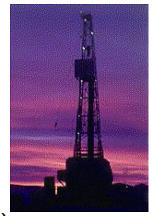
Strategic Center for Natural Gas

Latest Success Story



- **Project Specifics**
  - Union Pacific Resources (UPR) Company
  - Rock Island #4 Well drilled in Wyoming
  - Deep horizontal well (15,000 TVD w/1,700 ft horizontal)
  - Greater Green River Basin (Tight Sand)
- **Results**
  - Production exceeded expectations (2.1 bcf in six months)
  - Based on well's success, six more wells planned
  - Gas bearing play covers 900 square miles potentially huge reserves
- **Project Demonstrates**
  - Successful partnership between industry and Government
  - Successful crosscutting of several key program elements
    - Deep gas; low perm; horizontal well; deep horizontal core

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Strategic Center for Natural Gas

Drilling, Completion & Stimulation Objectives

- **Faster**
  - New bit technology & slim hole
- **Deeper**
  - High temperature & pressure
  - Develop smarter drilling systems
  - Increase penetration rates in hard rock
- **Cheaper**
  - Reduce cost of drilling in shale, low-perm, & deep water
  - Develop cheaper horizontal & multilateral wells
- **Cleaner**
  - Develop cost effective, environmentally friendly drilling technologies to increase access to federal lands using a small footprint.

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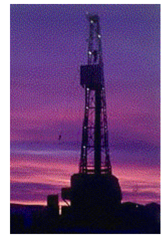
U.S. Deep Gas Resource



- **Need for deep gas is growing**
  - 7% of U.S. gas production 1999 - 14% in 2010
  - Depths > 16000 ft below the surface
- **Significant Deep Gas Resource**
  - Rocky Mountains - >40 TCF
  - Mid-Continent - >28 TCF
  - Norphlet - >25 TCF
  - Texas Gulf Onshore - >20 TCF
  - Permian Basin - >15 TCF

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Deep Gas
Barriers and Issues

- **Cost to drill and produce is extremely high**
  - High temperature, high pressure, extremely hard rock, greatly increased trip time
- **Probability of success much lower**
  - High rate of dry holes (exploratory & development)
- **Inadequate geologic & reservoir information**
- **Significant resource has access restrictions**
  - Example: rocky mountains
- **Industry R&D funding is at critical low**
- **FY2000 DOE Gas E&P funding level is insufficient**

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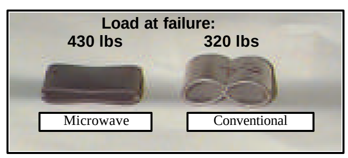
Ongoing NETL Activities

- **Resource Assessment**
  - USGS prioritization/evaluation effort underway
  - Texas BEG evaluation of deep gas in shallow GOM
- **Technology Development**
  - New drill bit technology (Novatek Mudhammer)
  - “Smart” drilling systems
    - Halliburton/Sperry-Sun, HTMWD & HTLWD
  - New materials

Strategic Center for Natural Gas

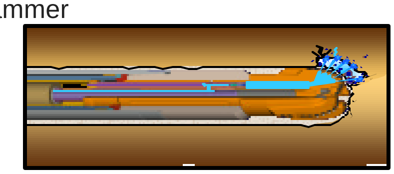
Revolutionizing the Drilling Industry

- **Microwave processing**
  - 30% stronger, less brittle, erosion/ corrosion resistant metals
  - Diamond and tungsten carbide can be formed together



- **Advanced composite drill pipe**
  - Half the weight of steel pipe
  - Potential for high speed data communication

- **High Performance Drilling Systems**
  - Jet assisted directional mud hammer
    - Higher ROP for hard rock
  - High pressure coiled tubing drilling system



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Deep Trek
Proposed Expanded DCS Program

- **Potential Technology Areas**
  - Low friction, wear resistant materials & coatings
  - "Smart" systems
  - Advanced sensors/monitoring systems
  - High performance drilling systems
- **Program Elements**
  - Develop key components
  - Demonstrate components
  - Integrate & demonstrate entire drilling system

Strategic Center for Natural Gas

Deep Trek Planning Workshop

- **Activities**
  - Obtain industry perspective
  - Identify key barriers & R&D opportunities
  - Develop collaborative R&D action plan for next 2-5 years
- **Breakout Sessions**
  - Drilling & completion fluids
  - Completion based well design
  - Advanced smart drilling systems
  - Drilling diagnostics & sensors systems
- **R&D Challenge**
  - Meet industry needs -Collaborative in nature
  - System mindset -Product focused

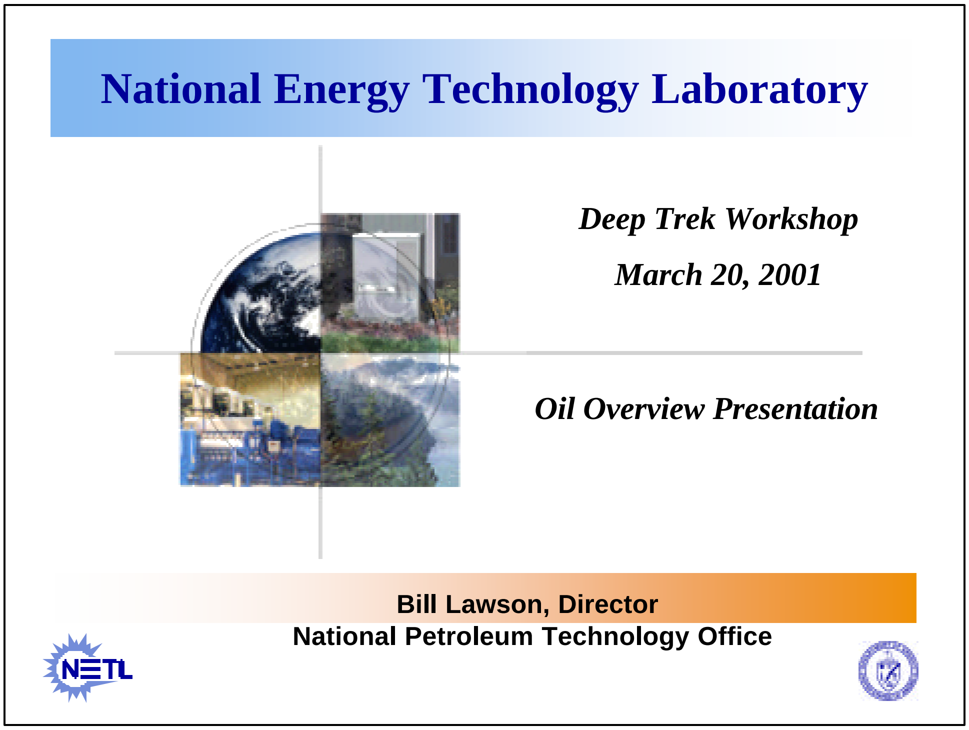
Strategic Center for Natural Gas

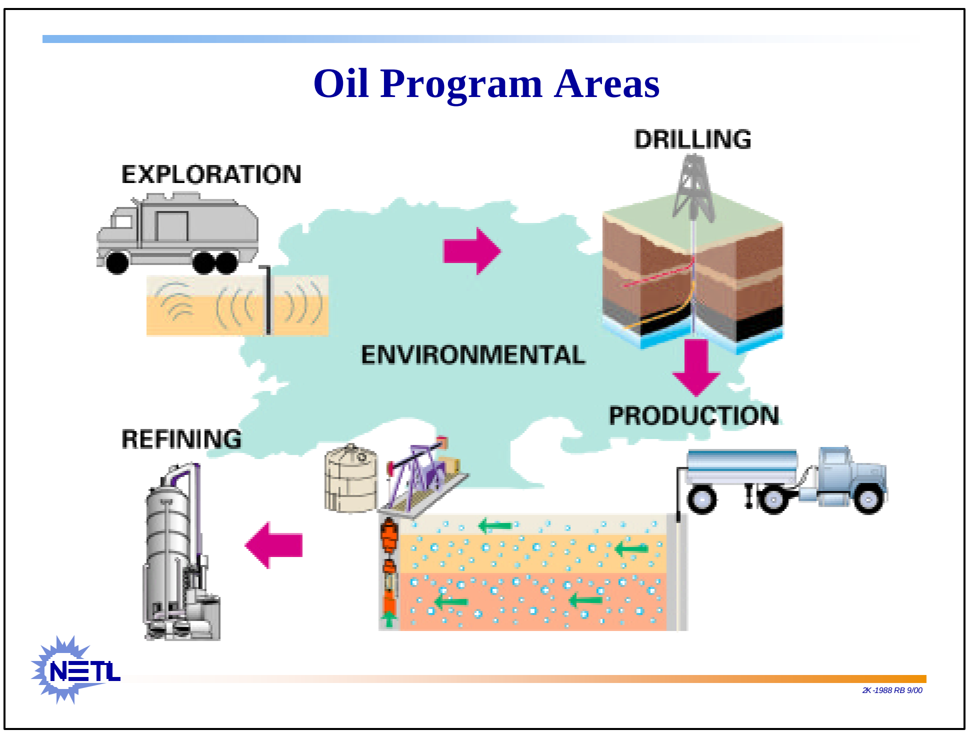
Internet Location: **netl.doe.gov/scng/index.html**

Strategic Center for Natural Gas

B. Oil Overview Presentation

Bill Lawson
National Energy Technology Laboratory, U.S. DOE


National Energy Technology Laboratory
Deep Trek Workshop
March 20, 2001
Oil Overview Presentation
Bill Lawson, Director
National Petroleum Technology Office
NETL


Oil Program Areas
DRILLING
EXPLORATION
ENVIRONMENTAL
PRODUCTION
REFINING
NETL
2K-1988 RB 9/00

Advanced Cuttings Transport Consortium

University of Tulsa

Goals:

- Develop systems for drilling faster, deeper, cheaper, cleaner and more accurately
- Develop innovative technologies and hardware to decrease operational footprint
- Design advanced completion and stimulation systems to improve well productivity

2K-1988 RB 9/00

Advanced Cuttings Transport Consortium

Benefits:

- Reduce drilling costs
- Minimize formation damage
- Lower environmental risks
- Reduce surface footprint onshore and off
- Improve access to culturally, environmentally sensitive areas

2K-1988 RB 9/00

Composite Materials Consortium

Composite Engineering Applications Center Consortium with Industry, other Government Agencies, and University of Houston

Purpose:
- **Composite materials development and applications**

Accomplishments:
- **Supervising static electricity experiments in support of development guidelines to address composite materials static charge issues in conjunction with Coast Guard**

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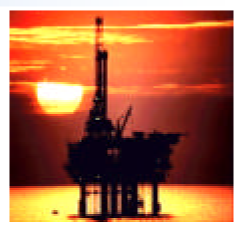
Composite Materials Consortium



Accomplishments:
- **Coordinated with MMS and Coast Guard to certify composites for offshore platforms**
- **Conduct multiaxial experiments to establish failure criteria and mechanics models for design and analysis**
- **Eight papers presented in 2000**

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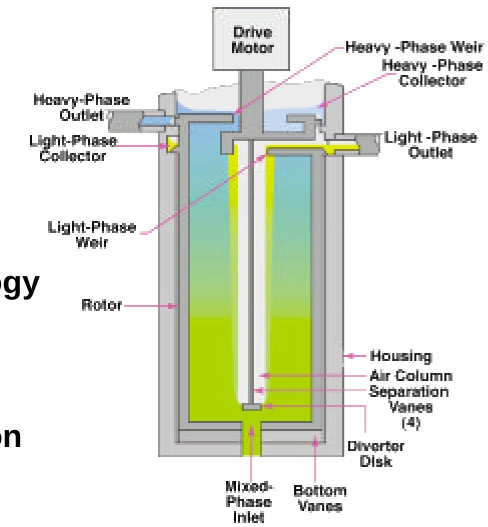
Downhole Separation Systems

Problem:

- Surface handling of produced brines is costly and increases opportunities for contamination



Objectives:

- Demonstrate technology
- Document costs and benefits
- Identify implementation regulatory barriers

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2K-1988 RB 9/00

Downhole Separation Systems

Accomplishments:

- Technology increased oil production by 50% and decreased surface water production by 95%
- Bench-scale tests show centrifugal separation provides good separation for feed streams containing from 10 to 95% oil
- Gas rates of up to 21% oil flow rates did not degrade separator operation

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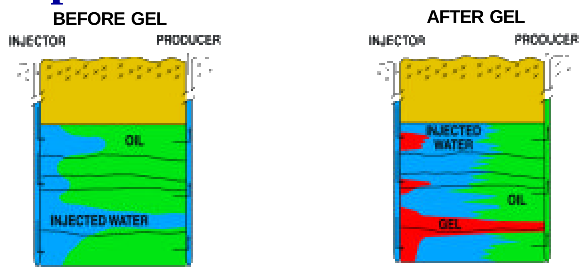
2K-1988 RB 9/00

Polymer Gel Treatment to Optimize Conformance



Problem:

- Water-breakthrough during flooding significantly increases operating costs ($100 million per year for each 1 percent water production increase)

Partners:

- Petroleum Research Recovery Consortium, BP, Chevron

2K-1988 RB 9/00

Polymer Gel Treatment to Optimize Conformance

Objective:

- Design polymer gel systems that selectively reduce water and gas production during oil recovery

Successes:

- Gel treatments reduced gas and increased oil in BP's Prudhoe Bay field by 22,000 barrels per day
- Gel treatments decreased BP's water production by 19,000 barrels per day with no reduction in oil recovery rates
- Gel treatments in Chevron's Rangely field, CO produced an additional 685,000 barrels of oil and recovered treatment costs in 8 months

2K-1988 RB 9/00

For more information

- Check our Webpage at www.npto.doe.gov or www.netl.doe.gov
- Call our office at 918-699-2001
- Fax a request to 918-699-2005

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C. GEOTHERMAL DRILLING RESEARCH AT SANDIA NATIONAL LABORATORIES

Sam Varnado
Sandia National Laboratories, U.S. DOE

Geothermal Drilling Research at Sandia National Laboratories

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Infrastructure & Information Systems
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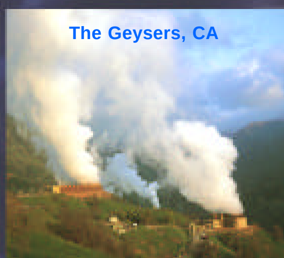
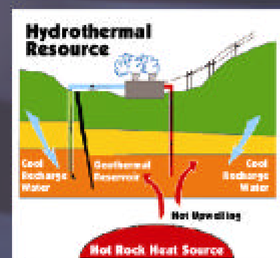
2001





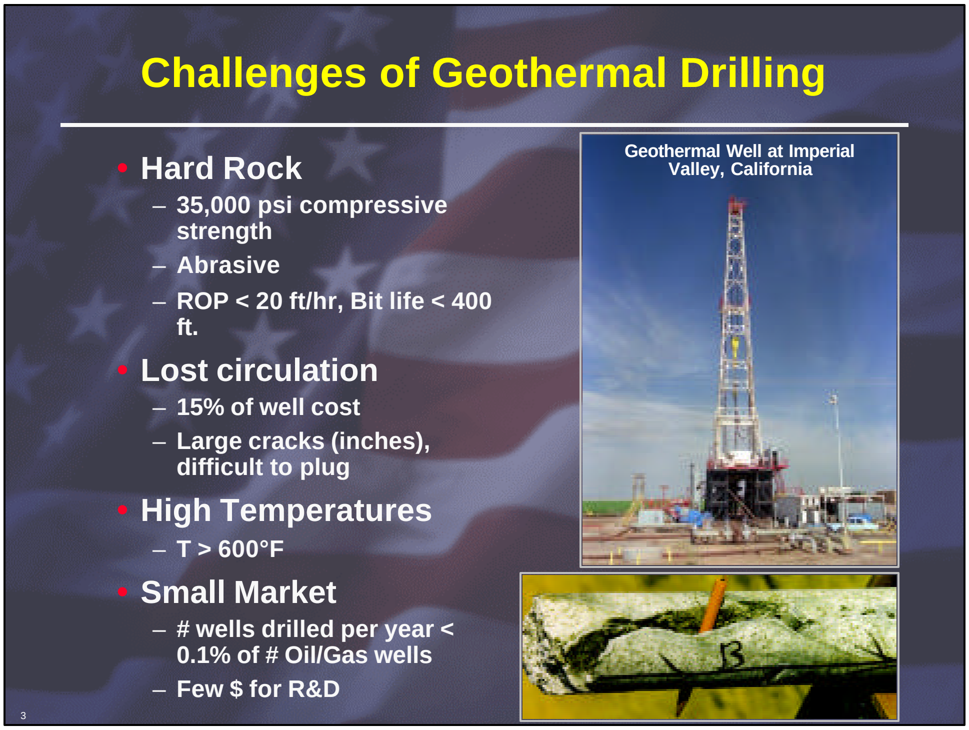
Drilling Research Program Focuses on Reducing Well Construction Costs

... increasing the nation's proven geothermal reserves and assisting U.S. industry to expand the use of geothermal heat & power

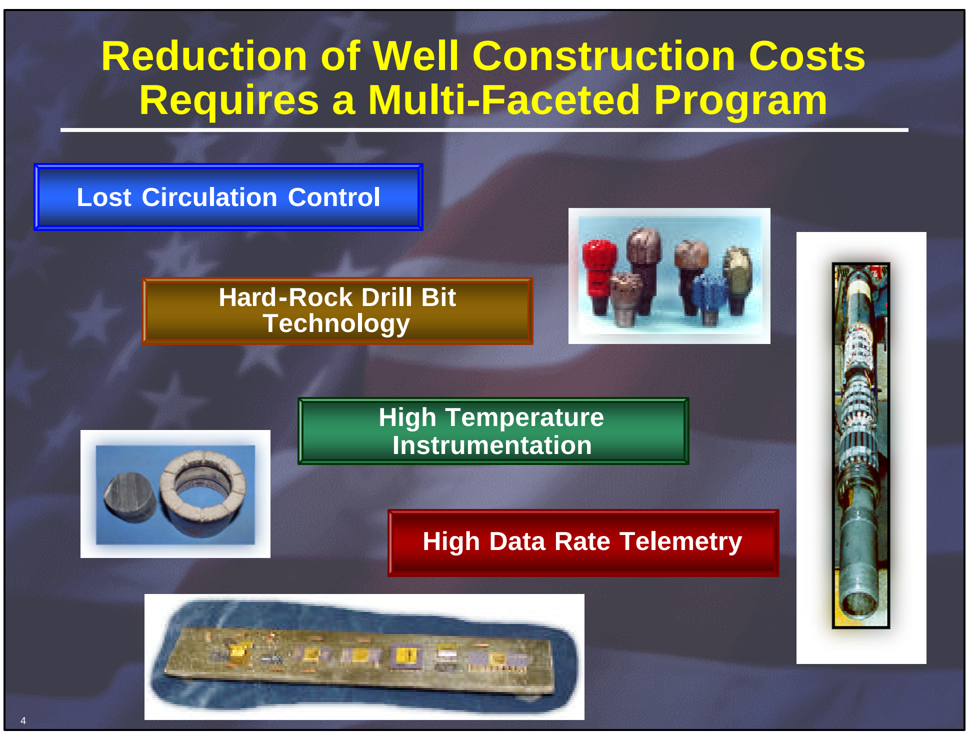
- **Conventional Drilling:**
  - Develop technology for reducing the cost of geothermal wells by 25% or more
- **Advanced Drilling:**
  - Reduce drilling costs by another 25% through revolutionary developments in technology
  - Focus is on a Diagnostics-While-Drilling system for process monitoring and control

35% - 50% of a Geothermal Project Cost Is in Drilling and Completion

2



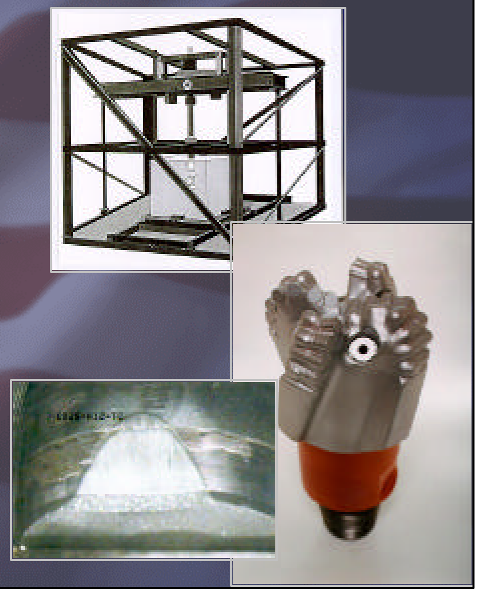
Challenges of Geothermal Drilling
Hard Rock
– 35,000 psi compressive strength
– Abrasive
– ROP < 20 ft/hr, Bit life < 400 ft.
Lost circulation
– 15% of well cost
– Large cracks (inches), difficult to plug
High Temperatures
– T > 600°F
Small Market
– # wells drilled per year < 0.1% of # Oil/Gas wells
– Few $ for R&D
Geothermal Well at Imperial Valley, California
3



Reduction of Well Construction Costs Requires a Multi-Faceted Program
Lost Circulation Control
Hard-Rock Drill Bit Technology
High Temperature Instrumentation
High Data Rate Telemetry
4

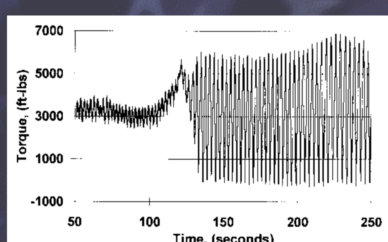
Hard-Rock Drill Bit Technology

- **Objective:** Develop technology to double ROP and bit life in high-temperature, hard-rock drilling
- **Approach:** Work with drill bit companies and researchers to improve drag bit performance in harder rocks through modeling, materials research and testing

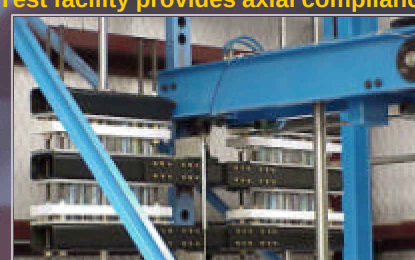


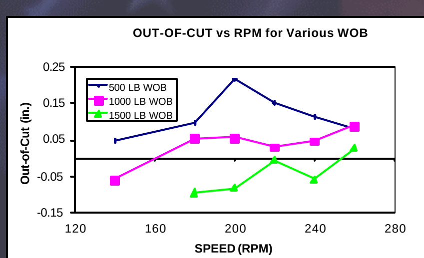
5

Vibrational Instability Limits PDC Bit Performance in Hard Rock



Test facility provides axial compliance





6

Sandia is Advancing HT Electronics for Downhole Applications

- Developing a simple unshielded data logger for 300° C
  - Components are presently becoming available for a 250° C data logger
- Developing new HT batteries for 150° C to 300° C operation
- Sharing information with American industries, HiTED (High-Temperature Electronics Downhole)
- Supporting SBIR initiatives for new 300° C components
  - Capacitors, large valued >10uF
  - MEM inclination sensors
  - High accuracy clock references
  - High accuracy pressure
  - Pressure/Temperature tool
- Developing HT, long-life fiber optics for sensing and downhole communications applications

7

We Are Testing Electronics At 300°C

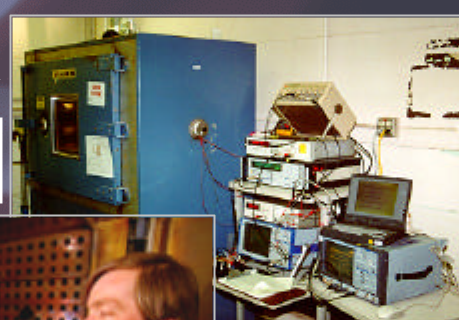
83C51 Microprocessor

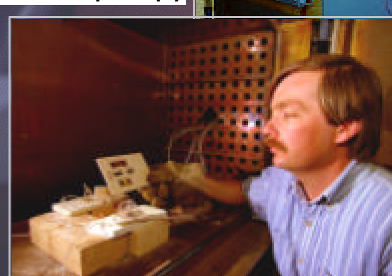
"Glue Logic" (54AC373, 54AC00)

Temperature Sensor Circuit (HT 1104 Op. Amp.)

32 Kbyte SRAM

Initial testing

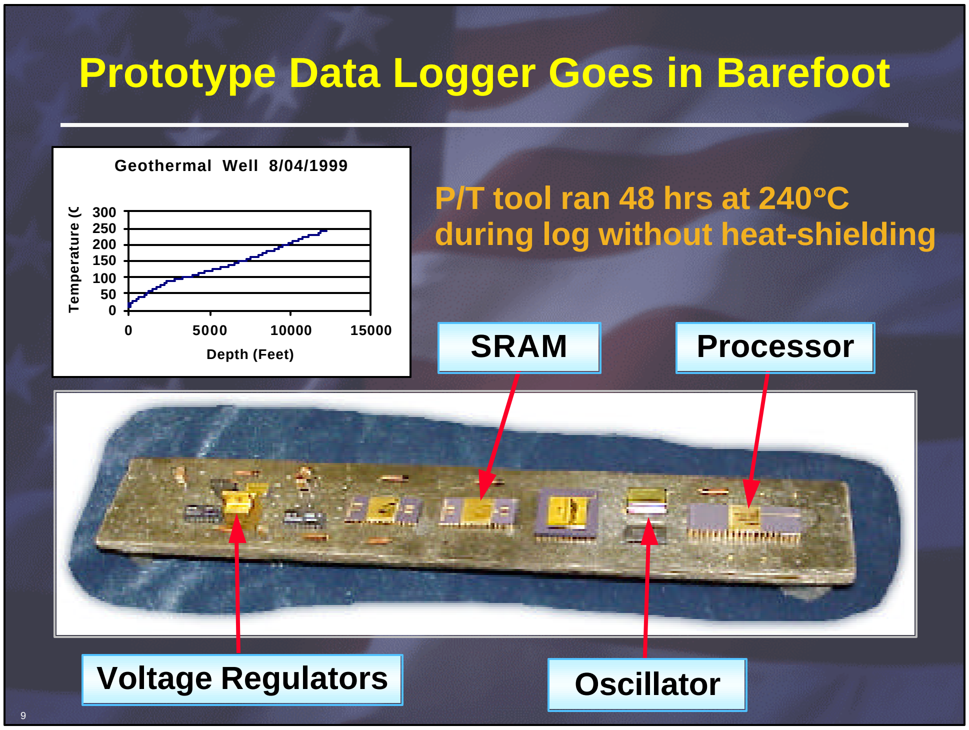




The above circuit demonstrated at HiTEN 98

Joe Henfling tested this first circuit to 300°C without failure.

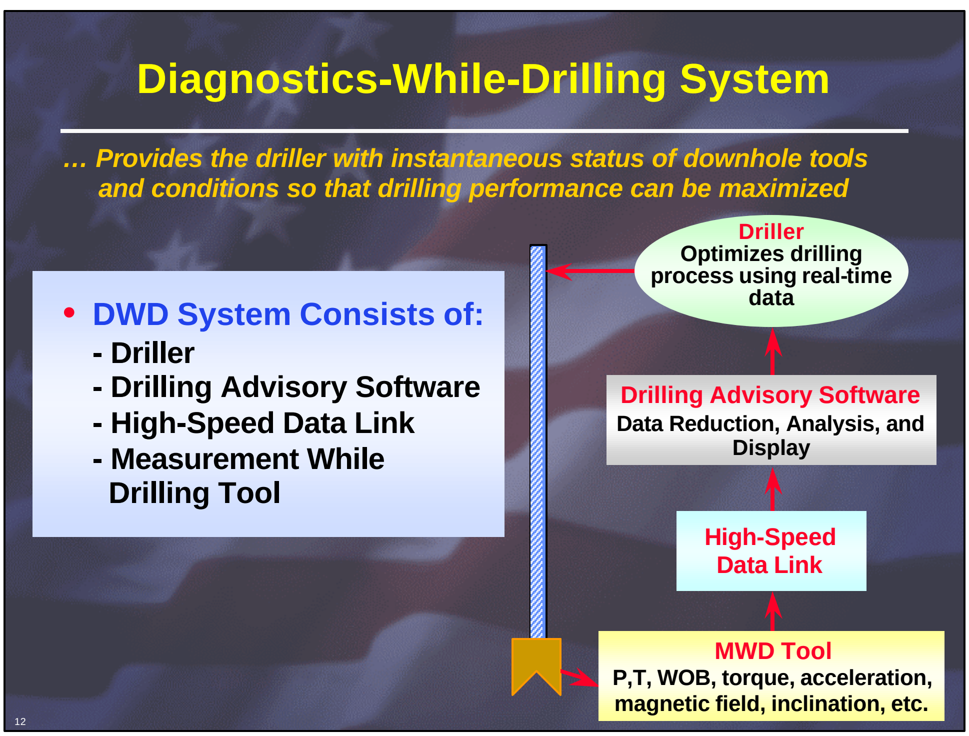
8

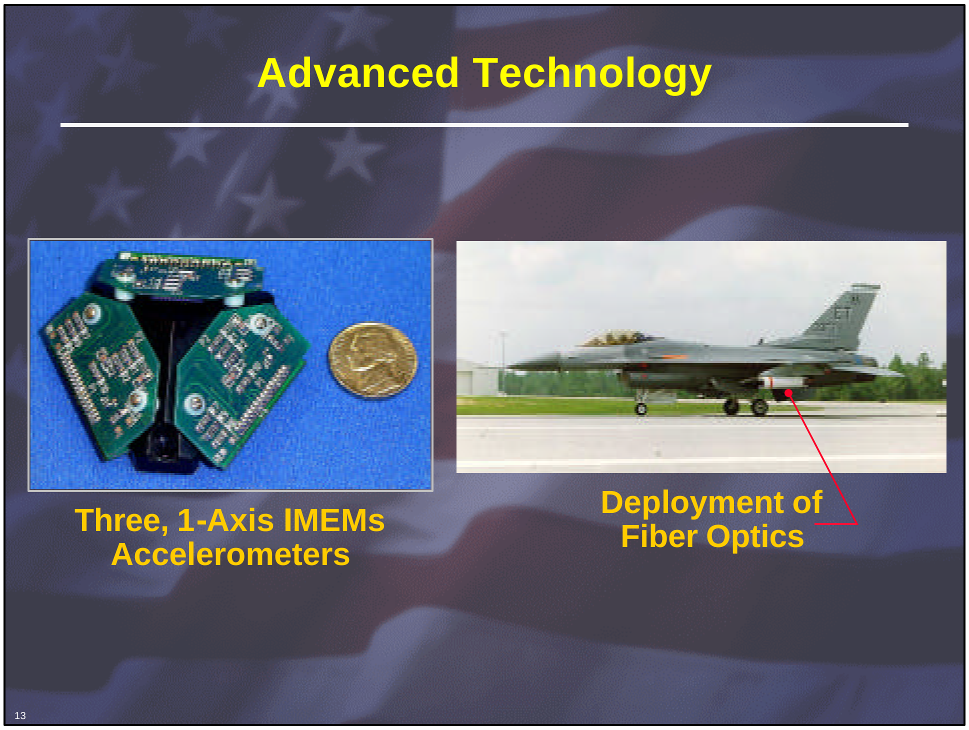


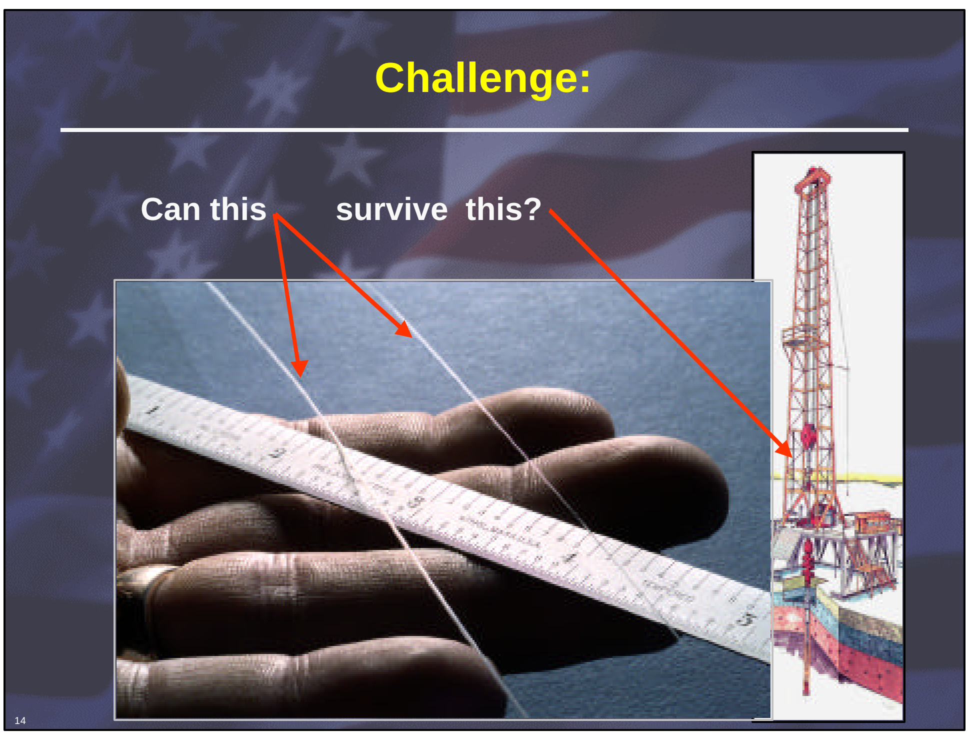
Prototype Data Logger Goes in Barefoot
Geothermal Well 8/04/1999
Temperature (C
300
250
200
150
100
50
0
0
5000
10000
15000
Depth (Feet)
P/T tool ran 48 hrs at 240°C during log without heat-shielding
SRAM
Processor
Voltage Regulators
Oscillator
9

High Data Rates Are Needed To Improve Drilling Efficiency
WOB and Torque While Bouncing Off Bottom at 70rpm & 30klb
WOB
TOB
70klb
30klb
0 lb
-30klb
7kft-lb
3kft-lb
-1kft-lb
1
SEC
2
10

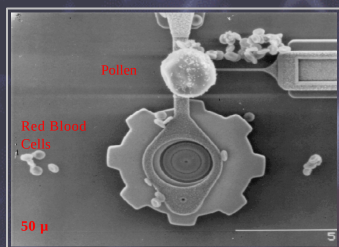

Acoustic Telemetry Can
Increase Data Rates
Acoustic Telemetry
Down-Hole Measurements
Temperature
Gas Influx
Gamma
Resistivity
Flow Rate
Well Dimensions
Direction
Sound waves travel through steel pipe and can be used to transmit data
These acoustic systems use frequency bands devoid of drilling noise
Drill pipe threads and tool joints do not block these signals
Two-way communication does not depend upon the condition or presence of drilling mud
11


Diagnostics-While-Drilling System
… Provides the driller with instantaneous status of downhole tools and conditions so that drilling performance can be maximized
DWD System Consists of:
- Driller
- Drilling Advisory Software
- High-Speed Data Link
- Measurement While Drilling Tool
Driller
Optimizes drilling process using real-time data
Drilling Advisory Software
Data Reduction, Analysis, and Display
High-Speed Data Link
MWD Tool
P,T, WOB, torque, acceleration, magnetic field, inclination, etc.
12

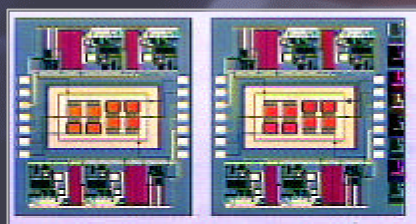

Advanced Technology
Three, 1-Axis IMEMs
Accelerometers
Deployment of
Fiber Optics
13


Challenge:
Can this
survive this?
14

Intelligent Micromachines: Keys to "The Next Silicon Revolution"



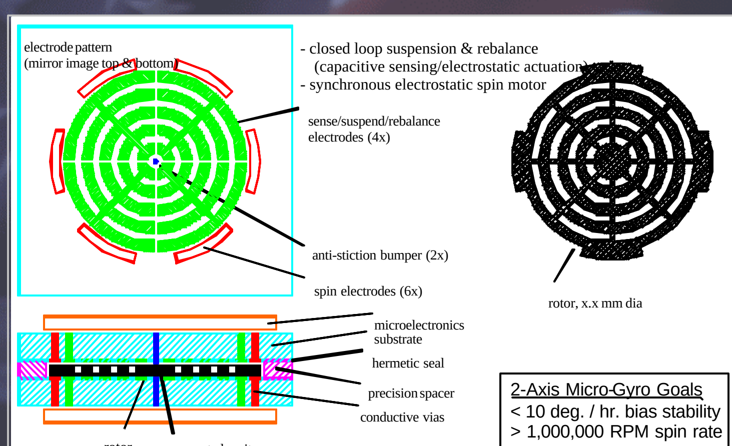
- Miniature mechanical systems with micron feature sizes
- Batch fabricated with no assembly required
- Exploits microelectronics infrastructure
- Common technology base for sensors, Actuators, and Electronics



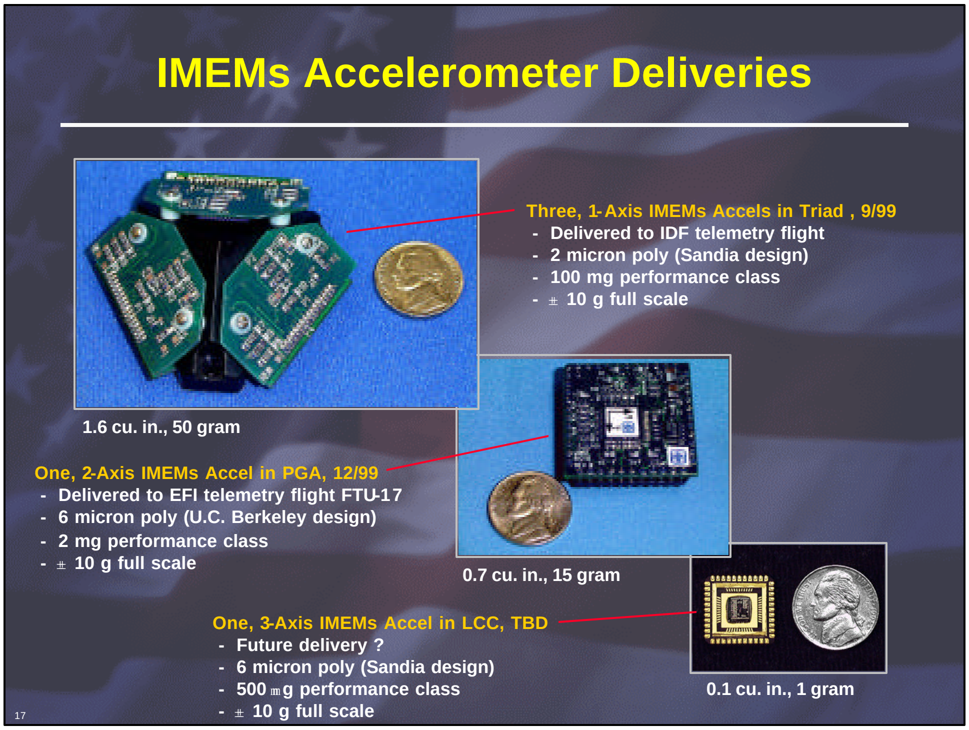
15

Spinning Mass Micro-Gyro

Hybrid MEMs, 2-Axis Gyro w/ Flip-chip Electronics



16


IMEMs Accelerometer Deliveries
Three, 1-Axis IMEMs Accels in Triad , 9/99
- Delivered to IDF telemetry flight
- 2 micron poly (Sandia design)
- 100 mg performance class
- ± 10 g full scale
1.6 cu. in., 50 gram
One, 2-Axis IMEMs Accel in PGA, 12/99
- Delivered to EFI telemetry flight FTU-17
- 6 micron poly (U.C. Berkeley design)
- 2 mg performance class
- ± 10 g full scale
0.7 cu. in., 15 gram
One, 3-Axis IMEMs Accel in LCC, TBD
- Future delivery ?
- 6 micron poly (Sandia design)
- 500 mg performance class
- ± 10 g full scale
0.1 cu. in., 1 gram
17

D. Madden Deep Unit Madison Wells
Fremont County Wyoming
Challenges & Wish List

Robert Soza
Burlington Resources

Madden Deep Unit Madison Wells
Fremont County Wyoming
Challenges & Wish List

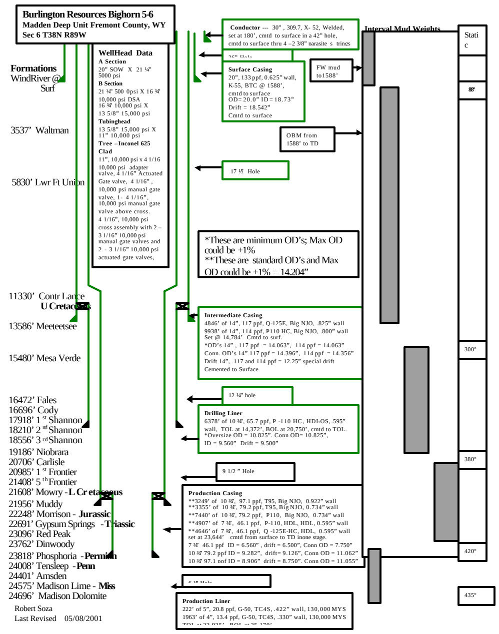
Robert Soza
Drilling Engineer
Burlington Resources

Deep Trek Workshop
March 20-21, 2001
Houston, Texas

Challenges

- Deep -- +/- 25,000' -- +/- one year to drill
- Large holes required for casing strings
- Crooked hole potential – shallow to +/-12,000'
- Hole stability issues with improper drilling fluids
- Fast drilling in large hole size requiring good hydraulics
- Slow hard drilling from 10,000' to TD
- Tight hole clearances for casing strings
- Overpressured and depleted formations from 5,000' to 24,000'
- Heavy casing strings – 2 strings over 1MM lbs
- Special rolling of most casing strings
- Hot -- +430^oF BHST
- Corrosive gases in the production stream -- +12% H_2S +20% CO_2

Wellbore Sketch



Where Do We Spend Our Time?

- 320 days thru running production liner
- 60 days on plateau – 19%
- 260 days drilling/tripping – 81%
  - 5143 drilling hours – 214.3 days = 82.4% of drilling days
    = 67% of total days
  - 1097 tripping hours – 45.7 days = 17.6% of drilling days
    = 14% of total days

Technology/Operations that Work on Madison Wells

- Downsized the hole vs. prior wells
- Diesel OBM
- Drilling large hole with bent motors
- Slow speed high torque motors
- PDC bits in 17 ½”, 16”, and 12 ¼” holes
- Long heavy casing strings with swaged connections
- Stabberless casing running
- Foam Cementing in one stage from 15,000’
- Diamond impregs and turbines
- Reverse circulation cementing on 24,000’ string of casing
- Monobore well design
- Use of CRA liner and tubing string
- Clad tubinghead and tree

Technology Wish List

- Whatever is done to improve technology for deep wells needs to be simple and have as few moving parts as possible – no moving components is excellent – i.e., we prefer fixed cutter bits to tricones due to less moving parts
- Large Diameter 17 ½”/16” Hole Section to 15,000’
  - More durable slow speed motors
    i.e., stator improvements
  - Tougher PDC bits – to drill sand/shale sequences
  - Cost effective straight hole drilling device
    We try to keep our holes under 1º deviation from surface to 15,000’
- Intermediate Hole Section 12 ¼” to 21,000’
  - Durable slow speed high torque motors – stator improvements
  - Tougher tricones – metal to metal seals, gage protection, etc.
  - More aggressive diamond impregs
    Cutting structure and hydraulics
    Impregs designed to cut shale and sand sequences at higher penetration rates
  - More effective lost circulation/well control strategies

Technology Wish List *(cont)*

- Deep Hole Section 9 ½ and 6 ½ hole from 21,000 – 25,000'
  - Higher torque turbines – But transmissions mean more moving parts
  - More aggressive diamond impregs for sand/shale sequences
    - Cutting structure and hydraulics
  - More durable diamond impregs for sand sections
  - Cementing techniques for long string
- Real time data manipulation between offset data, rock compressive strengths, PVT data, formation 6" ahead of the bit, etc.
  - Aggregation techniques vs. paper now
- Ways to slim deep holes
  - Reduce the casing to hole clearances – i.e., run 11 ¾ liner in 12 ½ hole or manufacture non standard casing sizes (14 1/8" OD with a 12 ¼ ID, 10 7/8" OD with a 9 ½ ID) to allow standard size bits to be used. Effective if hole stability is not an issue. If a casing string could be run that did not require cementing, i.e., the casing had a mesh, external coating that could be activated downhole and provide the annular seal – the above issues could be resolved and allow us to downsize holes – i.e., drill faster.

E. Deep Trek Presentation

John Shaughnessy
BP

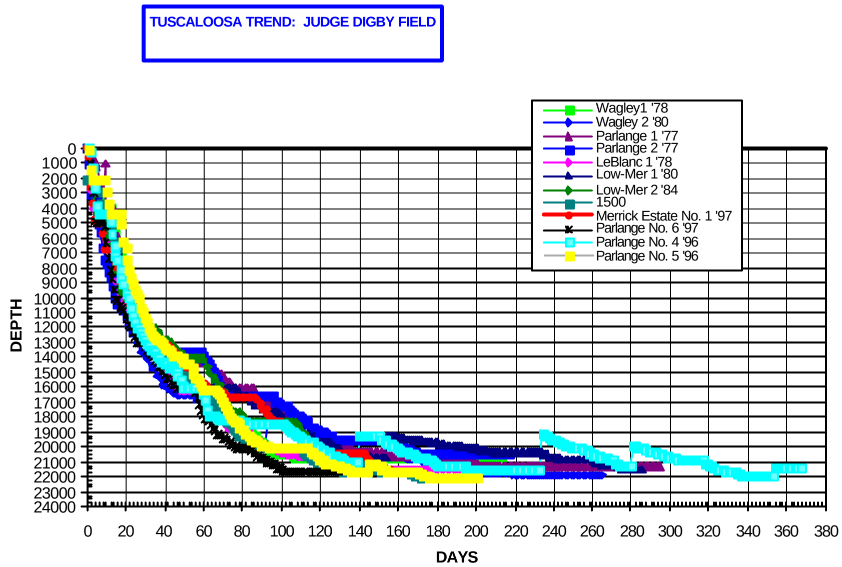
Deep Trek Presentation – Summary
John Shaughnessy, Drilling Engineer, Houston

- BP is actively drilling deep wells in Louisiana.
- High interest in improving ROP deep.
- Most of time spent in deepest part of well.
- Trouble time (NPT) is largest factor in well's ultimate cost.
- Most trouble time occurs deep.
- Most trouble is associated with bit trips.
- Reducing bit trips has a multiple effect on the ultimate well cost.

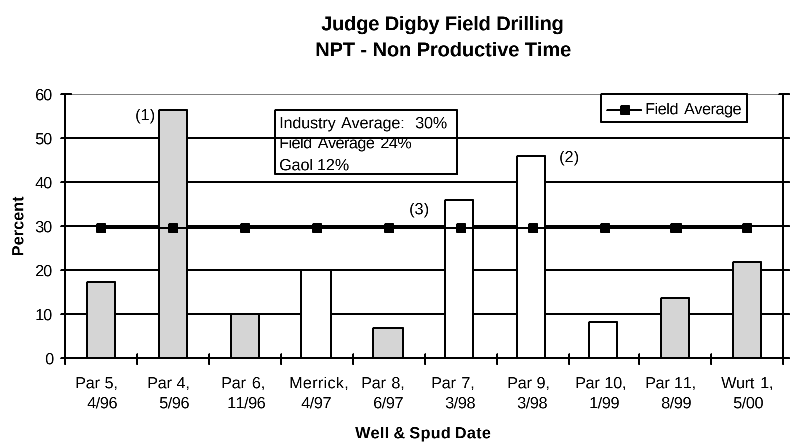
Improving ROP

- Over 50% of rig time is spent in the last 10% of the hole.
- Drilling faster directly cuts rig time and saves money.
- It also cuts down on the number of bits required so the benefits are multiplied.
- Most problems are associated with trips.

Drilling Time Curves Showing High Percentage of Time in Deepest Part of Well



Comparison of Non-Productive Time. Deep Wells have more NPT. Most NPT happens deep in the well. Most NPT problems are associated with bit trips.



Where can drilling engineer impact cost?

- Location costs are driven by the area.
- Casing Points are set by pore pressure.
- Casing sizes are driven by flow requirements
- Rig size and capability driven by casing and depth.

- Impact cost with ROP.

How Impact ROP?

- Bit Selection
- Hydraulics – more pump, more flow rate, bigger drill pipe
- Overbalance against the formation (or under-balance)

Cost Driven Basin

- Improving ROP cuts well costs
- Improves cycle time

- Driving costs and time down improves the economics – fewer reserves are required per well.

F. Deep Drilling Problems

William Maurer
Maurer Technology

A Noble Drilling Corporation Subsidiary

Deep Drilling Problems

Dr. William C. Maurer

DOE Deep Trek Workshop

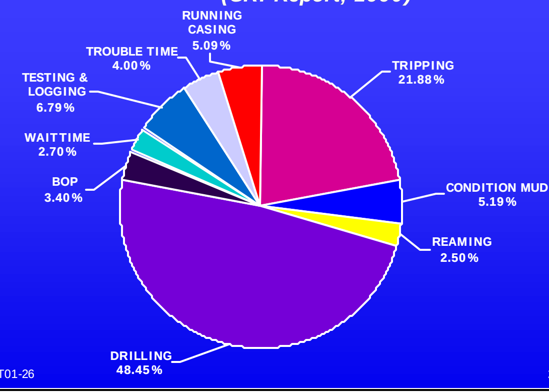
Houston, TX

March 20, 2001

TT01-26 1

Deep Well Drilling Time Breakdown

(GRI Report, 1990)



TT01-26 2

Deep Drilling Concept Rankings

(GRI Report, 1990)

Drilling Concept	Ranking
PDC/TSD Bits	31.10
Slim Holes	30.98
Roller Cone Bits	29.58
Down Hole Motors	28.20
Top Drives	28.13
Coiled Tubing	27.70
Optimized Drilling	26.45
MWD Equipment	25.48
Automated Rig	23.70
High Pressure Jets	21.03
Casing While Drilling	18.30
Explosive Drills	13.70
Thermal Drills	11.53

TT01-26 3

Deep Well Drilling/Completion Problems

Problem	Cause
Low drilling rates	Hard rock, chip hold-down
Short bit life	Abrasive rock, impact loading
Slow trips	Deep wells
High casing costs	Multiple strings, deep wells
Motor failures	High temperature
MWD failures	Vibrations, high temp
High drilling cost	Large rig, low ROP, casing
Casing wear	Long drilling time

TT01-26 4

Deep Well Drilling/Completion Problems (Cont.)

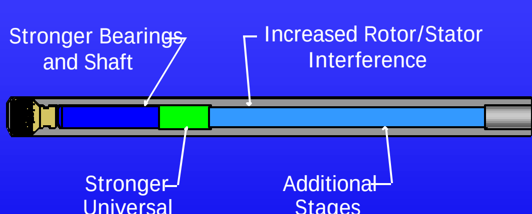
Problem	Cause
Mud thermal degradation	>350^{0}F
High mud ECDs	Small holes, long intervals
Poor cement bond	Poor mud displacement
Lost circulation	High cement density
Cementing liners	Sealing lap joints
Packer failures	Small diameter, high temp
Corrosion	High Temp, CO_2, H_2S
Underbalanced Drilling	Gas compressibility

TT01-26 5

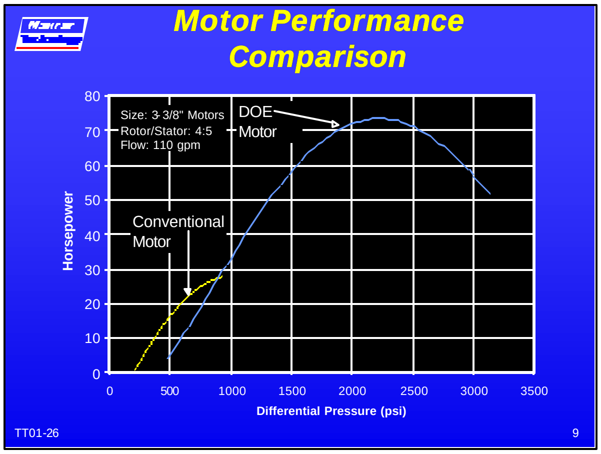
High-Power Motor

TT01-26 6

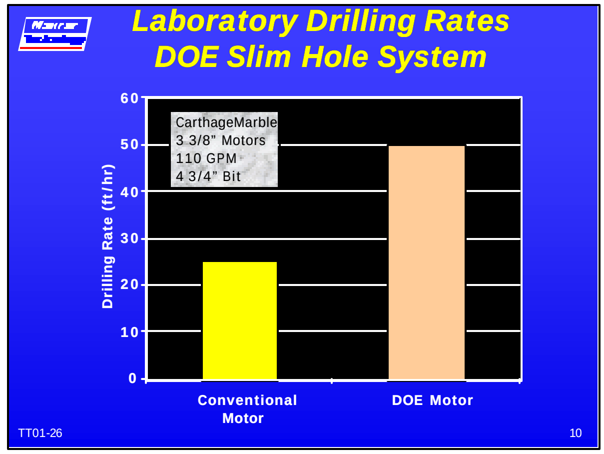
DOE High-Power Motor Design



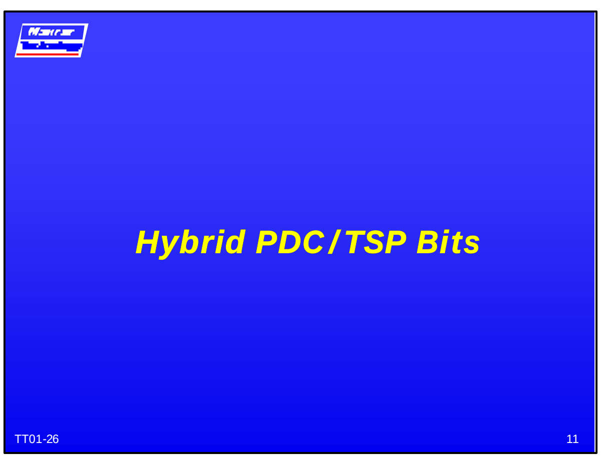
TT01-26 7



Motor Performance Comparison
Size: 3-3/8" Motors
Rotor/Stator: 4:5
Flow: 110 gpm
DOE Motor
Conventional Motor
Horsepower
Differential Pressure (psi)
0
10
20
30
40
50
60
70
80
500
1000
1500
2000
2500
3000
3500
TT01-26
9

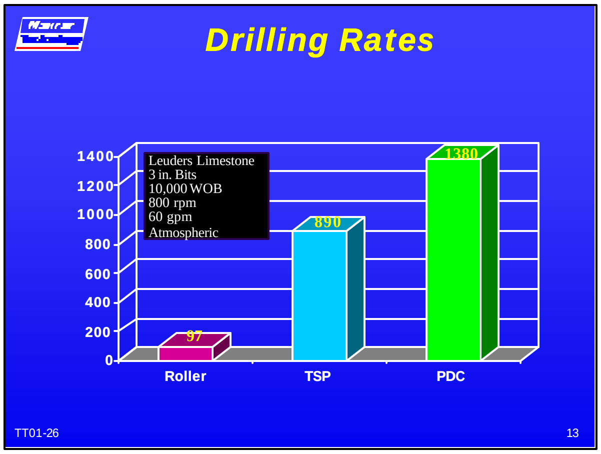


Laboratory Drilling Rates DOE Slim Hole System
CarthageMarble
3 3/8" Motors
110 GPM
4 3/4" Bit
Drilling Rate (ft/hr)
0
10
20
30
40
50
60
Conventional Motor
DOE Motor
TT01-26
10

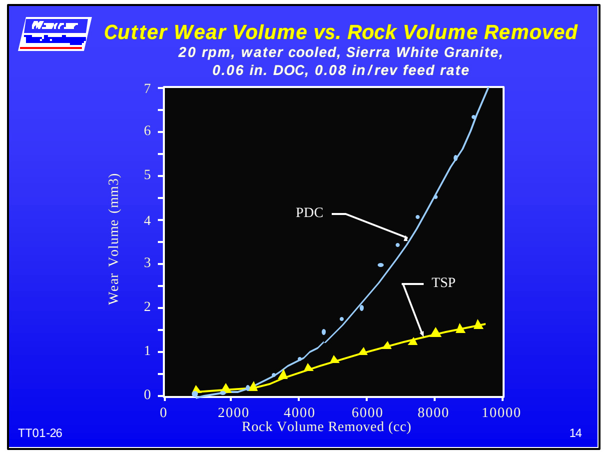


Hybrid PDC/TSP Bits
TT01-26
11

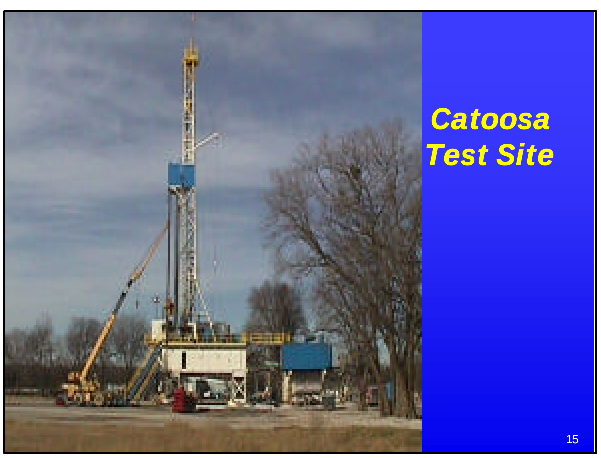
DOE Hybrid TSP/PDC Bit



Drilling Rates
Leuders Limestone
3 in. Bits
10,000 WOB
800 rpm
60 gpm
Atmospheric
1400
1200
1000
800
600
400
200
0
97
890
1380
Roller
TSP
PDC
TT01-26
13



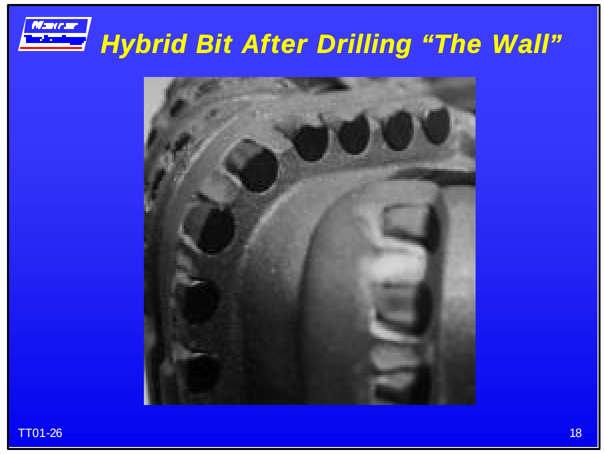
Cutter Wear Volume vs. Rock Volume Removed
20 rpm, water cooled, Sierra White Granite,
0.06 in. DOC, 0.08 in/rev feed rate
Wear Volume (mm3)
PDC
TSP
0
2000
4000
6000
8000
10000
Rock Volume Removed (cc)
TT01-26
14

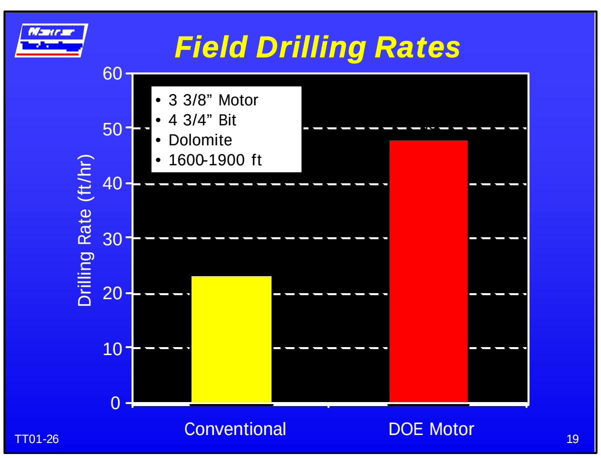


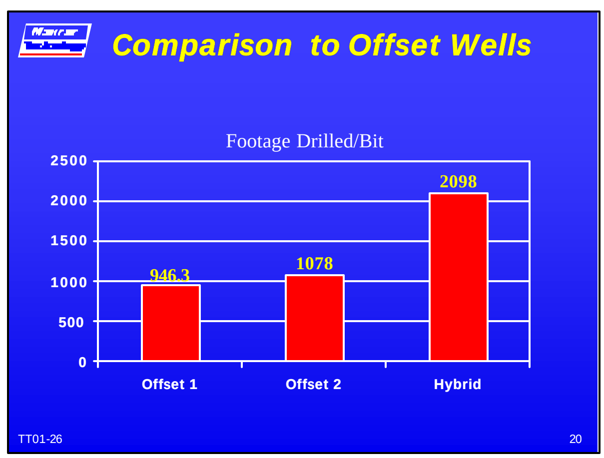
Catoosa
Test Site
15

DOE Motor In Derrick

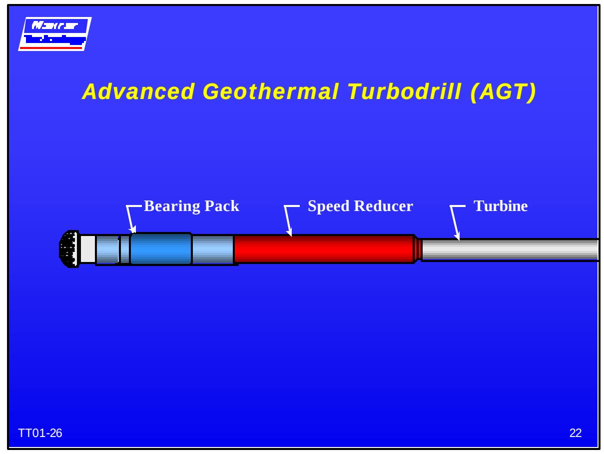

Attaching Hybrid Bit to DOE Motor

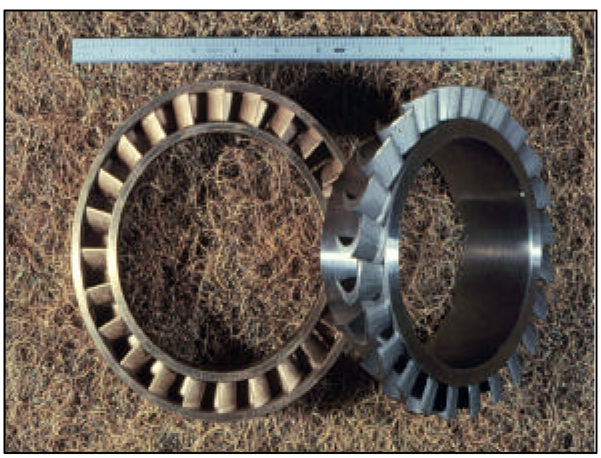

Hybrid Bit After Drilling "The Wall"
TT01-26
18

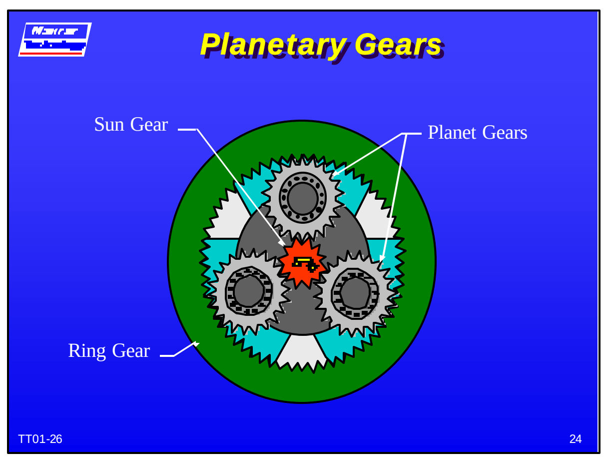

Field Drilling Rates
• 3 3/8" Motor
• 4 3/4" Bit
• Dolomite
• 1600-1900 ft
Drilling Rate (ft/hr)
60
50
40
30
20
10
0
Conventional
DOE Motor
TT01-26
19


Comparison to Offset Wells
Footage Drilled/Bit
2500
2000
1500
1000
500
0
946.3
1078
2098
Offset 1
Offset 2
Hybrid
TT01-26
20

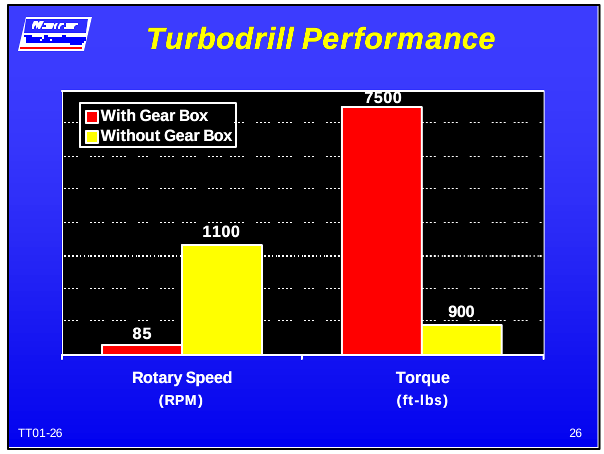

High Power Geared Turbodrill
TT01-26
21


Advanced Geothermal Turbodrill (AGT)
Bearing Pack
Speed Reducer
Turbine
TT01-26
22

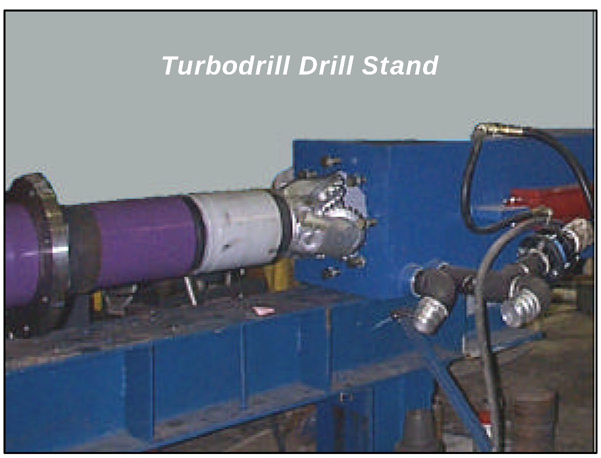



Planetary Gears
Sun Gear
Planet Gears
Ring Gear
TT01-26
24

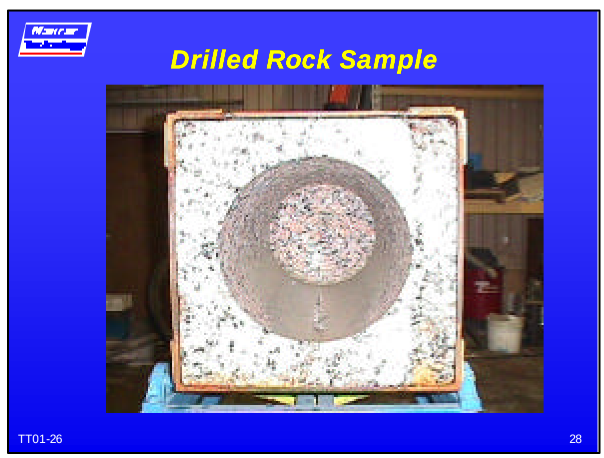
VECTOR OIL TOOL
Speed Reducer Shafts and Gears
Lower Sun Gear
Upper Sun Gear
Planet Gear
TT01-26
25



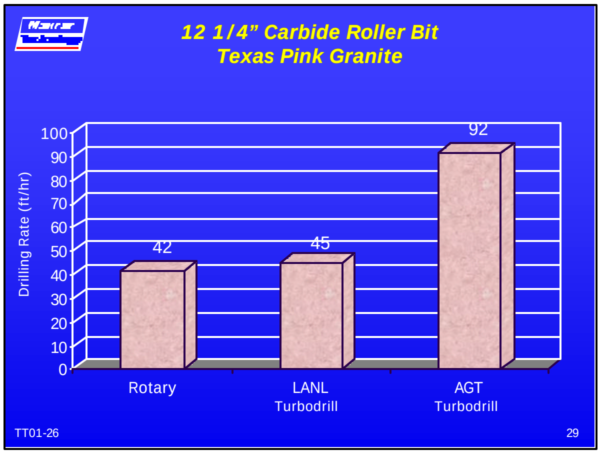
Turbodrill Performance
With Gear Box
Without Gear Box
7500
1100
900
85
Rotary Speed
(RPM)
Torque
(ft-lbs)
TT01-26
26

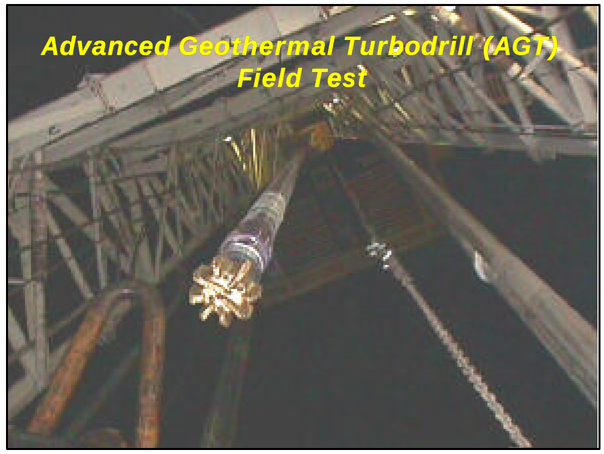


Turbodrill Drill Stand

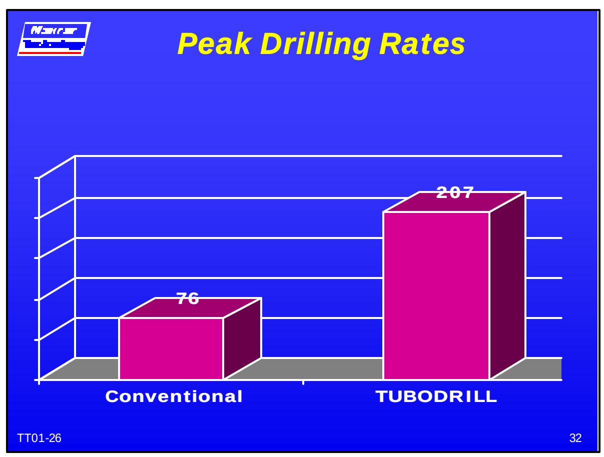


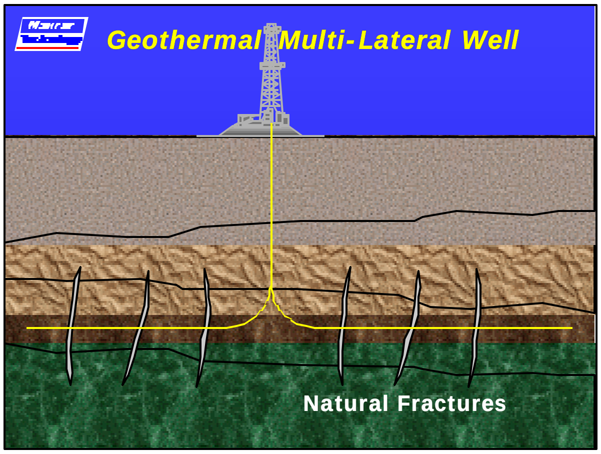
Drilled Rock Sample
TT01-26
28


12 1/4" Carbide Roller Bit
Texas Pink Granite
Drilling Rate (ft/hr)
100
90
80
70
60
50
40
30
20
10
0
42
45
92
Rotary
LANL Turbodrill
AGT Turbodrill
TT01-26
29

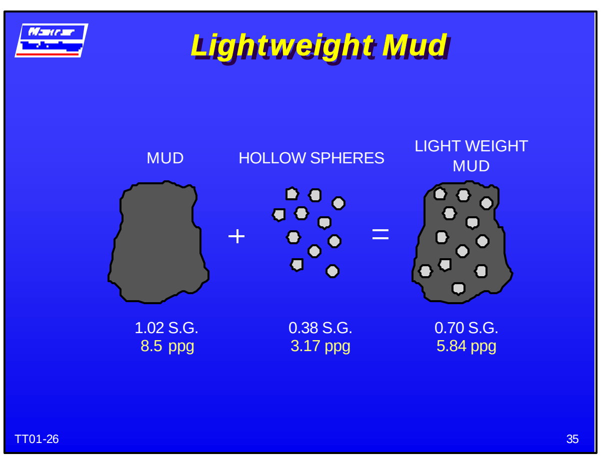

Advanced Geothermal Turbodrill (AGT) Field Test


Christensen Bit
31

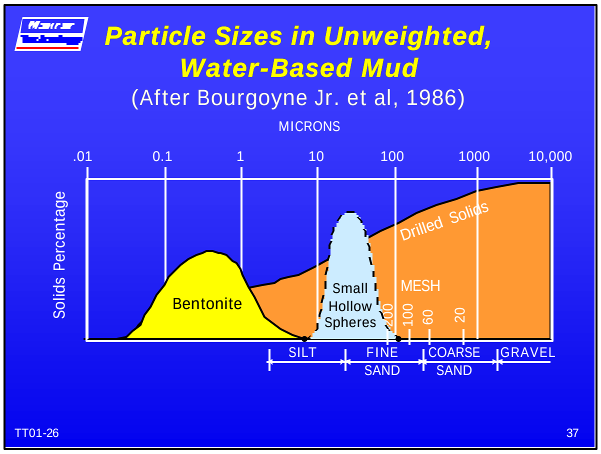

Peak Drilling Rates
76
207
Conventional
TUBODRILL
TT01-26
32


Geothermal Multi-Lateral Well
Natural Fractures


Deep Well
Lightweight Mud
TT01-26
34


Lightweight Mud
MUD
HOLLOW SPHERES
LIGHT WEIGHT MUD
+
=
1.02 S.G.
8.5 ppg
0.38 S.G.
3.17 ppg
0.70 S.G.
5.84 ppg
TT01-26
35

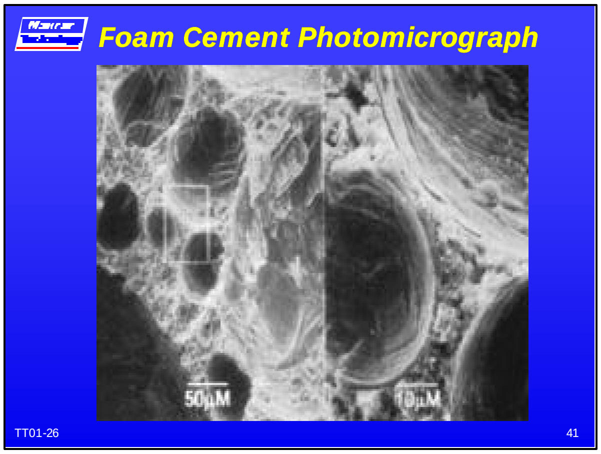

Glass Beads
TT01-26
36


Particle Sizes in Unweighted, Water-Based Mud
(After Bourgoyne Jr. et al, 1986)
MICRONS
.01
0.1
1
10
100
1000
10,000
Solids Percentage
Bentonite
Small Hollow Spheres
Drilled Solids
MESH
100
60
20
SILT
FINE SAND
COARSE SAND
GRAVEL
TT01-26
37


Golden State Drilling Rig Mud System

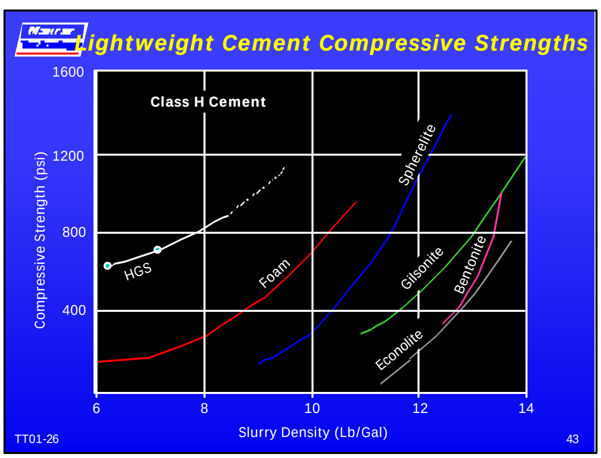

Mud Returns
TT01-26
39


Lightweight Cement
TT01-26
40

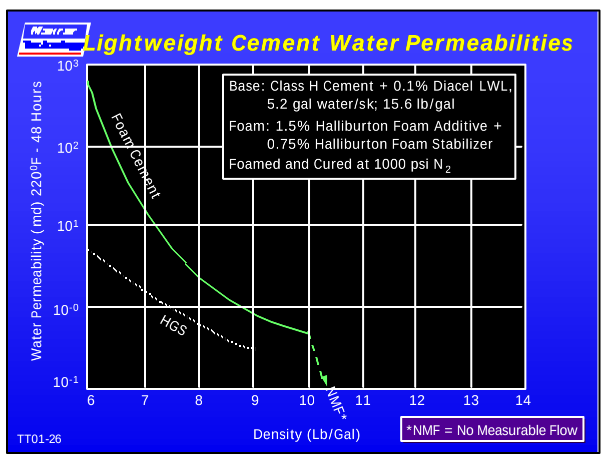


Foam Cement Photomicrograph
50µM
10µM
TT01-26
41

Lightweight Cement
16.0 ppg
TT01-26
42

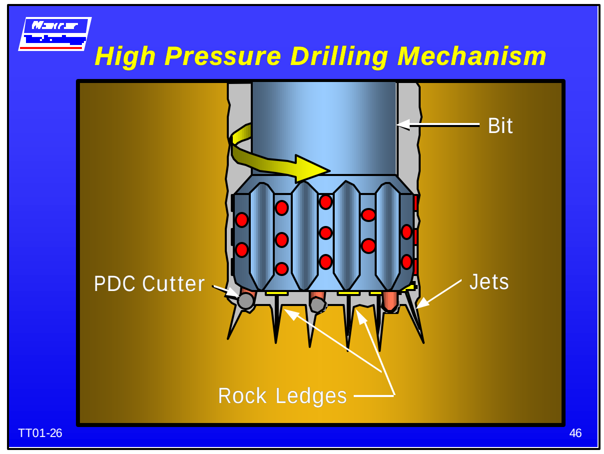


Lightweight Cement Compressive Strengths
Class H Cement
Compressive Strength (psi)
1600
1200
800
400
HGS
Foam
Spherelite
Gilsonite
Bentonite
Econolite
6
8
10
12
14
Slurry Density (Lb/Gal)
TT01-26
43

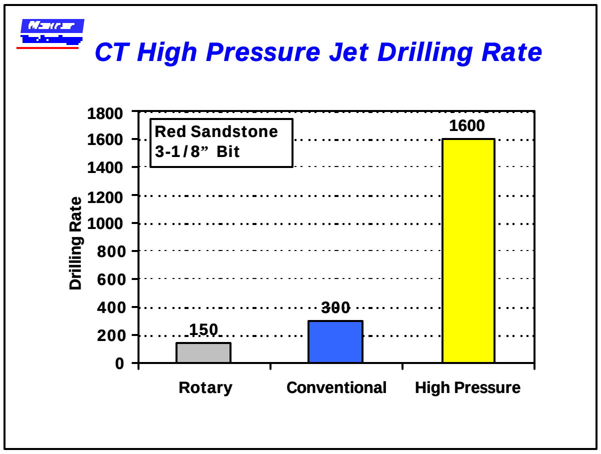


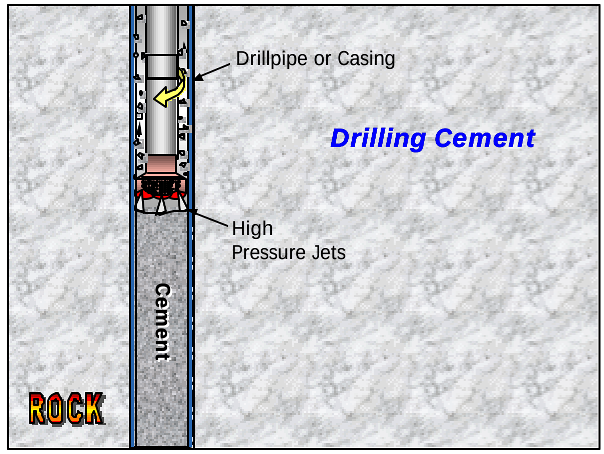
Lightweight Cement Water Permeabilities
Base: Class H Cement + 0.1% Diacel LWL, 5.2 gal water/sk; 15.6 lb/gal
Foam: 1.5% Halliburton Foam Additive + 0.75% Halliburton Foam Stabilizer
Foamed and Cured at 1000 psi N_2
Water Permeability (md) 220°F - 48 Hours
10^3
10^2
10^1
10^0
10^{-1}
Foam Cement
HGS
NMF*
6
7
8
9
10
11
12
13
14
Density (Lb/Gal)
*NMF = No Measurable Flow
TT01-26


High Pressure CT Jet Drill
TT01-26
45


High Pressure Drilling Mechanism
Bit
PDC Cutter
Jets
Rock Ledges
TT01-26
46

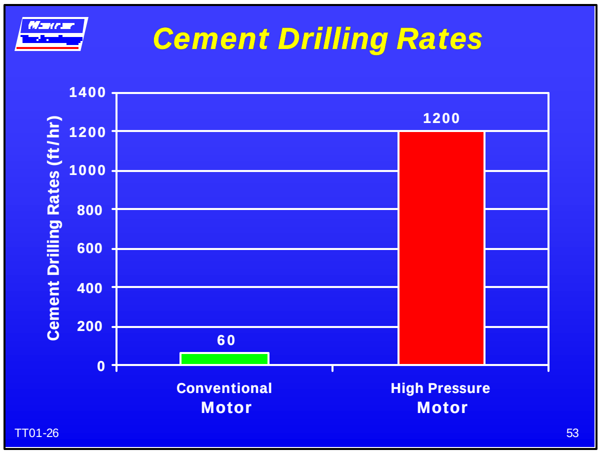

High Pressure Motor
10,000 psi


CT High Pressure Jet Drilling Rate
Red Sandstone
3-1/8" Bit
Drilling Rate
1800
1600
1400
1200
1000
800
600
400
200
0
150
300
1600
Rotary
Conventional
High Pressure

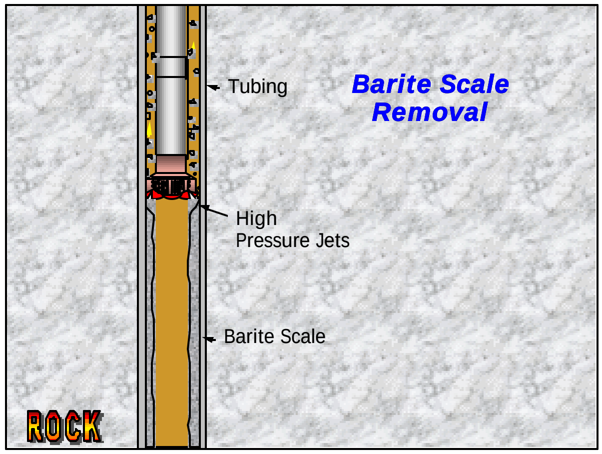

Drillpipe or Casing
Drilling Cement
High
Pressure Jets
Cement
ROCK


Tubing Filled With Cement


Tubing After Drilling Cement

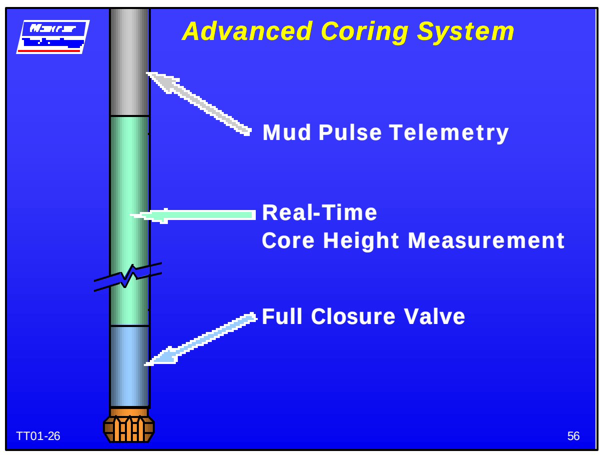


Cement Drilling Rates
Cement Drilling Rates (ft/hr)
1400
1200
1000
800
600
400
200
0
60
1200
Conventional Motor
High Pressure Motor
TT01-26
53

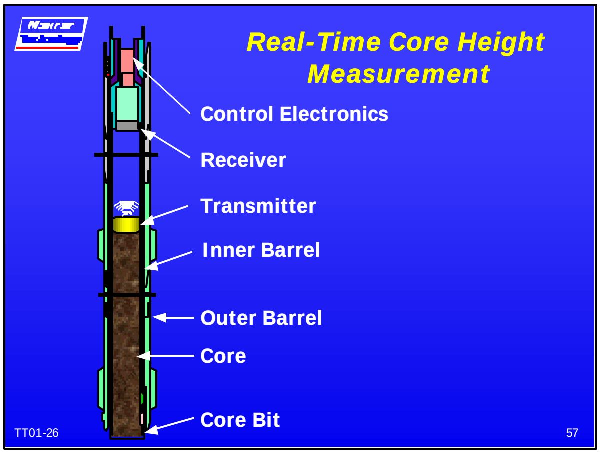


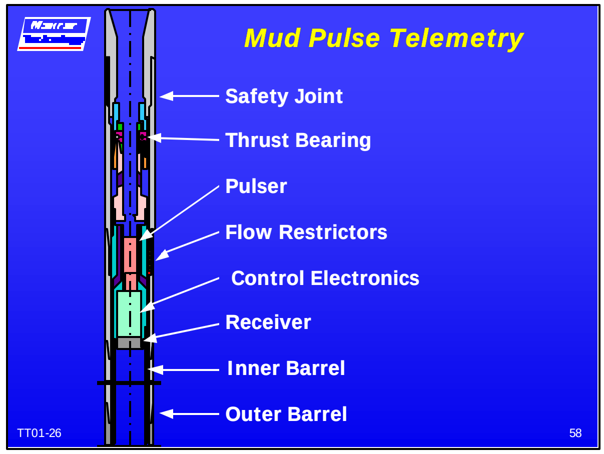
Barite Scale Removal
Tubing
High Pressure Jets
Barite Scale
ROCK

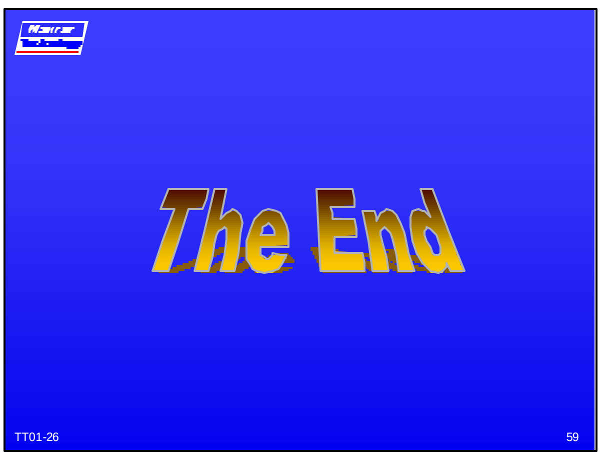
Advanced Coring System
TT01-26
55



Advanced Coring System
Mud Pulse Telemetry
Real-Time
Core Height Measurement
Full Closure Valve
TT01-26
56


Real-Time Core Height Measurement
Control Electronics
Receiver
Transmitter
Inner Barrel
Outer Barrel
Core
Core Bit
TT01-26
57


Mud Pulse Telemetry
Safety Joint
Thrust Bearing
Pulser
Flow Restrictors
Control Electronics
Receiver
Inner Barrel
Outer Barrel
TT01-26
58


The End
TT01-26
59

G. Perspectives on Deep Drilling Technology: Concerns and Challenges

William von Eberstein
Shell Exploration and Production Company

Perspectives on Deep Drilling Technology: Concerns and Challenges

William von Eberstein
Senior Drilling Superintendent
Shell Exploration and Production Company

Deep Trek Workshop
March 20-21, 2001
Houston, Texas

Drilling and Completion Fluids

- Gas Hydrate Inhibition (additives)/remediation – Problems associated with connectors and well control
- Deepwells +25,000' in ultra-deep water
- Fluid HTHP vs. HT, LT, HP combination of ultra-deep water environment – riser effect (radiator)
- Loss circulation material innovations for severe cases
- Water base muds with stable rheology, lubricity, high ROP
- SBM with stable rheology, lubricity, temp and inhibition which will pass minimum toxicity requirements of NPDES . LAO replacement—Degradation requirements must be met by new regulations
- Minimum cuttings retention properties and equipment to recover base at<6-8%
- Drill in fluids for horizontals wells (drilling/completion) with exceptable properties (i.e., low solid brines with high density, stable properties (TCP) in DW environment of low temp/high temp/pressure/low temp, environmentally friendly – salt saturated
- Cement technology – high angle hole plugs –slurries more tolerant of contamination

Well Designs

- HPHT motors/turbines with minimum pressure drop with shock absorption
- Bits for hard/abrasive rock (bi-centers and/or reamers)
- HP swivel packings to 7500 psi
- Light wt. risers for drilling and production
- Side-tracking technology utilizing non-metallic materials which meet design criteria (burst, wear, collapse, compression)
- BHA modeling and drillstring vibration determination
- Moorings in ultra-deep water (+5000') – support vessels (Ic. Lavney) critical ops
- Deepwell – well control and prevention – expandables STE
- Pore pressure measurement real time

MWD Technology

- Quality Control/Assurance of all technologies and equipment
- HPHT tools (+25,000 psi, 350 temp) – with shock resistance
- Data transmission contingencies (w/o pump to recover recorded data)
- Rotary Steerable systems that are reliable
- Reliable surface controlled expandable stabs/reamers for hard rock application
- Capacity to handle flow rates of +500 gpm
- Large hole size sonic tools
- Hole caliper data for large holes
- Seismic ahead of bit (reliable)
- Enhanced kick/flow detection. Capability to determine fluid type (gas, water oil).

Wire Logging

- New systems to replace drillpipe assist for high angle deep wells (i.e., self propelled tools)

Well Design

- SSSV for HP
- CRA for HPHT wells
- Multi-lateral HPHT wells with valves seals reliable at HP
- New technology/process for Pre-well design pore pressure determination (I.e., VACT inaccuracy common and expensive)
- Dual gradient drilling (SSPS)
- High pressure SSWHS and trees (+25,000 psi)

Other

- Proven Handling equipment for 750 ton – slips/elevators
- Large bore wellhead designs for additional casing contingency
- SSPS (subsea pumping system) – Dual Grad mud systems
- New design completion equipment to accommodate compact rig designs for drilling/completions/well interventions
- HP Pressure marine riser designs (I.e. 1500-2000 psi) for ultra DW applications (I..e, well control, gas in riser, subsea completions)
- Mud motors – capable of shock absorption, high torque
- Government support for road improvements and waterways to logistics staging points to increase logistics efficiency
- New drilling PDC bit designs for hard rock.

APPENDIX A: BREAKOUT SESSIONS

I. ADVANCED SMART DRILLING SYSTEMS – GROUP A

Participants
Advanced Smart Drilling Systems - Group A

NAME	ORGANIZATION
Fereidoun Abbassian	BP
Buddy Bollfrass	Ocean Drilling Program
John H. Cohen	Maurer Engineering
Gary Collins	Conoco, Inc.
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Michael Fripp	Halliburton
Leonard Graham	National Energy Technology Laboratory
Craig Ivie	Schlumberger Drill Bits
Jeff Jean	ACPT, Inc.
Arnis Judzis *	TerraTek
Ray LaSala	U.S. Department of Energy
Jim Leslie	ACPT, Inc.
Roy Long	National Energy Technology Laboratory
Hum Mandell	NASA Johnson Space Center
William Maurer	Maurer Engineering
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Jay Muthusami	Knowledge Based Systems, Inc.
Hans Neubert	ACPT, Inc.
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John Peters	Chevron Petroleum Technology
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Earl Shanks	Transocean Seoco Forex
Bill Stringfellow	Hydril Advanced Composites
Bil Thedtke	Technology International
Ajay Verma	Knowledge Based Systems, Inc.
Bill von Eberstein	SEPCO
Glen Warner	Chevron Petroleum Technology
Steve Williamson	Omsco Industries

**Report out presenter*

FACILITATOR: Alicia Dalton, Energetics

Advanced Smart Drilling Systems – Group A
What Are the Barriers to Cost Effective Deep Drilling?

Temperature		Information Transmission and Processing	Skills and Personnel	Pressure	ROP	Rig	Cost	Tubular Limits	Other
Electronics	Materials								
• Temperature issues – Seals for tools – PDM reliability – Sensors • Silicon technology (IC's etc.) (with respect to MWD) • MWD limit 195°C LWD limit 175° C = Smart drilling depth limited • Lack of high temperature electronics ✪✪✪✪ • MWD sensors which will survive extreme environments ✪✪	• Temperature issues – Seals for tools – PDM reliability – Sensors • High temperature drilling motors ✪✪✪✪ • High temperature tools ✪✪ • Lack of materials for motors at high temperature • Motor failure at high temperatures • Lack of development of high temperature polymers and resins ✪✪✪✪✪✪✪ • High temperature battery (low cost, too) ✪✪ • Cementing at high temperatures • Stable high temperature packer elements	• Telemetry and down hole power ✪✪ • Lack of real time drilling data ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ • Limited knowledge of down hole drilling conditions (real time) ✪✪ • Low data rate, no "real time" capability ✪✪✪ • Limited down hole data • Need to understand the down well environment better ✪ • Low/no speed reliable 2-way communication down hole • Down hole monitoring ✪ • Large amount of data to be handled • High rate data transmission from bit to surface ✪✪✪ • Data rate for up/down hole to allow knowledge of conditions and control (wired drill pipe) • Poor information about formation (ex. Pore pressure) • (Reliability) Signal/ Power across drill pipe joint • Measurement of in situ conditions (pressure, temperature, pore fluid) • Lack of reliable, low cost, miniature signal/power receiver/ sender ✪✪ • Subsurface hazards (e.g. depleted zones)	• No HPHT training • Personnel in strong price "time" • Access to drilling engineers ✪✪ • What does a drilling engineer need to go deeper, faster, cheaper • Resistance to change	• High pressure effect on seals • Lost circulation ✪ • Pore pressure ahead of bit ✪✪ • Swivel packings max 5800 psi • High pressure drilling system 20 ksi or greater ✪ • MWD pressure limitations • High pressure	• Rock strength • Bit technology • No aggressive drag bits for hard rock ✪✪✪✪✪✪✪✪✪ • Low ROP • ROP last 10-20% of hole • ROP increase X2 to justify cost • Hard rock performance (e.g. ROP) • Multiple trips ✪ • Rock variability (need smart bit) • Long trip times • Bi-center bit technology	• Drilling rigs designed for shallow holes ✪✪✪✪✪✪ • Flow rates required (tool damage) • Hydraulic limits ✪✪ • Power delivery is difficult T*N or Q*P	• High cost of rotary steerable systems • Cost-effectiveness of materials for harsh environments ✪✪ • Economics (for lower rate wells) • DW cost effective rigs (outside GOM) • Too many casings • Current tools too expensive for land operation and don't always cut costs • Tool reliability ✪✪✪✪✪✪	• Drill string/ Tool reliability ✪ • Drill string drilling in long wells • Long drill strings • Vibrations (drill string dynamics) ✪✪✪✪✪✪✪✪✪✪✪✪ • Drill string/ Casing wear • Hole angle/ drilling severity control/ measurement (limit fatigue/ wear) cost effective • High tubular weights at deep depths ✪✪✪	• Identification of fluid entries and character • Drilling fluid technology Rheology high/low temperature & high pressure ✪ • Logistics Marine/Air • Difficulty in testing tools ✪✪✪✪✪✪ • Too many obstructionist rules, regulations, environmental regs, partners, etc.

✪ = Vote for priority topic.

Advanced Smart Drilling Systems – Group A
What Are the R&D Opportunities to Overcome the Barriers?

ROP	Materials	Best Practices/ Techniques	JIP	Vibration	Down Hole Data/Info	Systems and Integration of Tools	Temperature
• Increase wear and impact resistance of PDC and TSP cutters • Soften rock with ultrasonics before drilling • Combination roller PDC bit ✪ • Optimize hole section drilling performance (ROP vs. life of bit) • "Morphing drill bit" optimizes itself for different formations • Constant WPB sub **OTHER** • Train personnel • Database for deep drilling technology	• Polymer electrolyte batteries • Nanotechnology sensors • Alternatives to steel for drilling string and casing – lighter, more corrosion resistant • Develop new materials for more aggressive drag bits • More wear resistant materials for tool joints • Motors with less reliance on elastomers but with high torque, moderate rpm • Improved component supply (electronics)	• Best practices for deep drilling ✪✪✪✪ • Low speed turbodrills • Improved inspection of drill pipe and BHA tools	• R&D work on "wired" tubing/drill pipe • Testing fund or JIP • Joint industry and government "materials" research program. • Joint industry commitment to specific financing tech costs i.e., commercial commitment ✪✪✪ • Tool joint development for "smart" inclusions ✪ • Field demo's of high tech/cost solutions for low budget/land applications	• Vibration dampeners within the drill string • Drilling systems with vibration control for use with drag bits ✪✪✪ • Controllable vibration dampeners • Drill string attenuator • Passive and active vibration control ✪ • Measurement of vibrations along drill string • Vibration absorbing materials ✪✪✪✪✪✪ • Develop cost effective smart systems to recognize vibrations down hole and eliminate them • Combined motor shock absorber	• Real time drilling data to optimize drilling process ✪✪✪✪✪✪✪✪ ✪✪✪ • Develop high information transmission technology ✪✪✪✪ • Electromagnetic data transfer ✪ • Seismic while drilling ✪✪✪✪✪✪ • Develop MWD drilling system • Diagnostics while drilling ✪ • Real time data/power transmission through drill string • Down hole intelligence • Develop high rate data system that is transparent to the rig operation and high temperature • Develop real time high data rate transmission and processing system • Down hole processing of data • Seismic interpretation for pore pressure • Pore pressure gamma sensors doable • Real time software applications – Rig site analysis – Pressure control – Well control • Closed loop drilling (real time data/control) to optimize bit/motor use	• Optimize system approach to rig design drillings system & equipment ✪✪✪✪✪✪✪✪ ✪✪✪ • Long wearing, impact resistant drag cutters ✪✪✪✪✪✪ • Smart drilling pipe ✪✪✪✪✪✪✪✪ ✪✪✪✪ • Faster drilling – Thermally stable diamond cutters – Bits which can be rotated at higher rpm in abrasive/ hard rock ✪✪✪ • Matched bits and motors • New seal initiative • 7500 psi mud seals are doable • Develop deep HPHT drilling rig • Rig with high pressure capabilities ✪✪ • Improved deep hole vibration monitoring • Reduce weight of drill string • Monobore well design ✪ • Laser drilling • Synthetic diamond technology for longer lasting PDC bits in hard rock ✪ • CWD • Casing drilling • Line-while-drill ✪ • Adaptive drill tool to alter bit dynamics • Match rig, hydraulic system drill string & data transmission to improve deep well ROP "Look at total system"	• Cool the mud to reduce effective down hole temperature • Increase temperature capability of materials ✪ • Hi temperature electronic component development ✪✪✪ • Limit temperature transmission to down string fluid flow ✪ • Silicon-on-insulator electronics ✪✪✪ • Develop high temperature composites ✪✪✪✪✪✪✪✪✪✪ • High temperature PDM • Develop high temperature MWD/LWD systems around new 250°C Honeywell chip • Develop high temperature polymers • Develop high temperature electronics • Sensors & electronics designed for HTHP

✪ = Vote for priority topic.

Advanced Smart Drilling Systems – Group A
What Actions to Take Advantage of R&D Opportunities?

OPPORTUNITY	ACTIONS	LEADERS	COLLABORATIONS	RESOURCES
PRIORITY #1 – **Real Time Data Transfer**	• Committee of government and industry formation to spearhead • State of the art (accomplishments) • Define problems/goals • Gap analysis • Re-evaluate economics of existing technologies • End user needs consideration • Determine value added • Identify potential solutions • RFPs	• Industry – Define problem • Government – Workshops for data collection	• Government/Industry (50/50) • Universities	• Government – Connections for team formation
PRIORITY #2 – **Real Time Data Instrumentation**	• Committee of government and industry formation to spearhead • State of the art (accomplishments) • Define problems/goals • Gap analysis • Re-evaluate economics of existing technologies • End user needs consideration • Determine value added • Identify potential solutions • RFPs	• Industry – Define problem • Government – Workshops for data collection	• Government/Industry (50/50) • Universities	• Government – Connections for team formation

PRIORITY #3 –
Optimize System Approach to Rig Design Drilling System and Equipment
	• Capture operations' needs
	• Integration
	• Define purpose
	• Identify critical components
	• Economics and contracting strategy
	• Review KTB approach
	• Review KTB results
	• Optimize ROP
	• Testing/Verification (test drill)
	• Assurance program
	• Commercialize
	• Outside industry perspective and possibilities
	• Demonstrate (field test)
	  – Laboratory testing
	  – Modeling
	• Publications
	• Lobby
	• Incentives
		• Rig operators and contractors
		• API, IADC, etc.
		• Operators
		• Government
			• Operators involved in planning, R&D, and solutions
			• Rig Operators
			• Contractors
			• API
			• IADC
			• Operators
			• Government
			• Service
				• Non-traditional JIP – Well commitment
				• Government
				  – Funding
				  – Demonstrations
				  – Upgrades
				  – Team formation
				• Contractors – Rig
				• Operators – Well

Advanced Smart Drilling Systems – Group A
What Actions to Take Advantage of R&D Opportunities? *(continued)*

OPPORTUNITY	ACTIONS	LEADERS	COLLABORATIONS	RESOURCES
PRIORITY #4 – Optimize ROP including Trip Time (Added by group)	• Identify limitations of current equipment – Reliability – Life – Material – Performance • Identify cost benefits • Gather data on various applications • Monitor and optimize drill string design (real time) • Bit to surface modeling • Study and improve hydraulics • Lab testing • Under balance drilling • Innovative drilling systems	• University • Government • Testing facilities • Tool manufacturers	• Operators for testing • Operators with suppliers • Everyone with DOE	• Operators – Data • Oil companies – Modeling data • Motor and bit companies – Data – Hardware – "Know-how"

II. ADVANCED SMART DRILLING SYSTEMS – GROUP B

Participants
Advanced Smart Drilling Systems - Group B

NAME	ORGANIZATION
Dave Bacon	Chevron
Ansgar Baule	Baker Hughes Inteq
Robert Coats	Baker Hughes Inteq
Blaine Comeaux*	Sperry-Sun
Mahlon Dennis	Dennis Tool Co.
Mark E. Freeman	Russlink Energy
Ali Kadaster	Anadarko
Jay Klassen	NEYRFOR Turbodrilling
Mike Pavelka	Kerr McGee
Jim Schumacher	Texaco
John Shaughnessy	BP
Damir S. Skerl	SDCI-Houston
Robert Soza	Burlington Resources
Bob Stayton	GTI
Sam Varnado	Sandia Labs

**Report out presenter*

FACILITATOR: Phil DiPietro, Energetics

Advanced Smart Drilling Systems – Group B
What Are the Barriers (Tech, Business, Market, Others)?

$	Rocks get hard (low ROP)	High T& P 25 kpsi, 400-600 F	Large hole size (due to telescoping)	Do not see what's going on	Inefficiency of the conveyance of energy from surface to rock face	Miscellaneous
• High cost of failure • Ability of service company to capture R&D benefits • High ROP = low service company revenues • Difficult to test equipment • Lack of longer term R&D funding by the industry • How do we handle commercial tool patents, competition with DOE funds? • Durability (capability) versus cost • Technology transfer	• Vibration induced failure of bit cutters and BHA components • No mud hammer with a weighted mud • Bit technology suitable for all formations • Variation of the strata • Gear reduction for turbines (cost, reliability) • Safety concerns associated with UBD (under-balanced drilling)	• Materials requirements versus availability • Temperature limitation of elastomers for PDMs (positive displacement motors • HTHP designs and testing for MWD and motors	• ROP • Volume of waste	• High-temperature sensors	• Higher standpipe pressures	• Sloughing of the hole

Advanced Smart Drilling Systems – Group B
What Are the Technology R&D Opportunities to Overcome Barriers?

MECHANICAL AND MATERIALS	DO NOT SEE WHAT'S GOING ON	ROCKS GET HARD	LARGE HOLE SIZE (TELESCOPING)	HIGH TEMPERATURE AND PRESSURE
• PDM motor with metal/ceramic seal ✪✪✪✪✪✪ • Seals that can withstand 25 kpsi ✪✪✪✪✪ • New swivel packing for 7.5 kpsi ✪✪✪✪✪	• Rig operator decision support system – Correlations between surface data & downhole – Look ahead of bit – NASA-type sensors ✪✪✪✪✪✪✪✪✪✪ • High temperature electronics and sensors that will work downhole ✪✪✪✪✪✪✪✪✪ • Formation-blind drilling apparatus (small diameter bits) ✪✪✪✪✪✪✪✪✪	• Under balanced drilling (replacement for conventional BOP systems, fluids that will change phase w/ choke pressure) ✪✪✪✪✪✪✪ • Better metallurgy for bits (microwave treatment) ✪✪✪✪✪ • Slim hole: adaptation of mining technology and procedures ✪✪ • Integrated motor/vibration dampener ✪✪ • "Different" rock destruction concepts (laser, hp water) ✪ • High-temp shock absorber ✪	• Drilling fluid or process that "cases" hole as you drill ✪✪✪✪ • Capability to drill a straighter hole (steerable drill) ✪ • Conventional slick casing with an expandable chemical coating – eliminate need for cement	• Continuous well cooling ✪✪✪ • Insulated drill pipe

✪ = Vote for priority topic.

Advanced Smart Drilling Systems – Group B
5-Year R&D Action Plan

	PRODUCT NEEDED	TASKS TO DELIVER PRODUCT	WHO DOES?
1	Rig operator decision support system • Open architecture • Applicable to all wells	• Form coalition to define standards for information systems • Develop logic algorithms for drilling operations. Two options, either think downhole or bring raw data to surface • Develop higher rate data transmission (e.g., acoustics, transistor in mud, fiber optics) • Upgrade temperature and pressure performance of sensors and electronics (look for other markets that could use similar technology in order to increase the production volume)	• Industry / government • Industry / government • Government / industry in advisory role • Government / industry
2	High temperature electronics and sensors that will work down hole >400^{o}F, 25,000 psi	• Develop basic HT electronic components • Develop HT batteries • Develop appropriate sensors	• Govt./academia/industry (advisory) • Govt./academia/industry (advisory) • Govt./academia/industry (advisory)
3	Formation-blind drilling apparatus	• Screen/assess existing innovations, equipment, methods, designs, and materials • Develop new concepts • Establish independent clearing house for arms-length evaluation of new concepts	• Government subsidizes industry-led field tests • Industry lead / government provide access to basic science and military technology (Petroleum Technology Transfer Council) • Government - no commercial royalty tie-ins or lock-outs
4	Develop new methods for well control that will enable safer UBD drilling in high-volume and high-pressure wells	• Provide seed money for concept development	• Government / industry
5	Mechanical components and materials for HTHP applications	• PDM motors with better seals • Develop swivel packing w/ 7,500 psi rating • Develop seals for numerous downhole components that can stand 25 kpsi, 400-600^{o}F, and exposure to corrosive chemicals • Transition from unit pricing to performance pricing	• Government / industry. One approach is for industry to fund an employee to work at a national lab for a 6-month or longer rotation • Industry (internal)

III. DRILLING DIAGNOSTICS & SENSOR SYSTEMS

Participants
Drilling Diagnostics & Sensor Systems

NAME	ORGANIZATION
Jim Albright	Los Alamos National Lab
Perakath Benjamin	Knowledge Based Systems, Inc.
Craig Cooley	Ussynthetic
Roger Entralgo	Energy Research Clearing House
Bill Hauser	MMS
Richard C. Haut	Halliburton Deepwater
Sudhendu Kashikar	Schlumberger
Buddy King	Nobel Eng. & Dev.
Jack Kolle	Tempress Technologies Inc.
Tom Laylock	Marathon Oil
Keith Millheim	Anadarko Petroleum Corp.
Mike Nero	Weatherford
Randy A. Normann	Sandia National Laboratories
Jack Pruitt	Halliburton Security DBS
Steven P. Rountree	Prime Directional Systems
Roger L. Schultz	Halliburton Energy Services
Gene Sparkman	Energy Research Clearing House
Charles Thomas	INEEL
Brad Tomer	NETL
Paul Tubel*	Tubel Technologies
Eddie Wright	Texas A&M/ODP
Jiang Wu	Chevron Petroleum

**Report out presenter*

FACILITATOR: Kevin Moore, Energetics

Drilling Diagnostics & Sensor Systems
What Are the Barriers/Issues (Tech, Business, Market, Others)?

Reliability and Capability	Industry Culture	Sensors	Formation	Bits and BHA	Data Management and Collection	Limitations	Cost
• Reliability of sensors and electronics • High temperature (kills electronics) • Motor life (low) • Motor diagnostics • Long term reliable electronics systems • Intelligent wells permanent sensors • Eliminate electric cables and hydraulic lines for completion reliability too low • Motor/BHA pressure drop too high • Pressure limited • High-temperature, long-term sealing technology (leakage through welds, elastomer failure)	• Lack of common agenda to attack problems • Resistance to change • Need "out-of-the-box thinking • He is not here. How could he help?	• Military components sharing • Exploit new sensor technology • Lack of industry knowledge of component 4C sensor usage • System high power consumption • Downhole power capacity and life • Pressure while drilling • What measurements are the priority (drilling) • Look ahead of the Bit	• High pressure, high temperature rock mechanics (understanding) • Deep multi-laterals (drilling and completion) • Casing collapse • "Safe" drill and produce gas simultaneously • Multiple pore pressures per well • Geo-steering • Do not know if we have deep gas • Measure of cutting remove/hole cleaning • Deep geo steering • Formation evaluation • Under balance • Formation damage during drilling • Drill motor/bit sensors requirements	• Bits to handle soft/hard rock combinations • Bit vibration and control • Unknown downhole drill string, BHA, bit actions • Event recognition • More durable bit cutting structures • Torque measurement capability	• Lack of data transmission ability (downhole) • Real time data analysis and application • Data management and integration • Data overload vs. data presentation for informed decisions • Data standard protocol • Real time data monitor form a remote location • How do we use the drilling diagnostic data – apply it to change what?	• People resources training • Lack of new deep iron • Older rig equipment	• Component cost effectiveness • Small diameter systems – 2 inch • Prototype high testing costs • Daily drilling and equipment cost

Drilling Diagnostics & Sensor Systems
What Are the Technology R&D Opportunities to Overcome Barriers?

Reliability and Capability	Sensors	Formation	Bits and BHA	Data Management and Collection	Industry Culture	Cost	Limitations
• Sensor system shock isolation • Electronic assemblies for high temperature (>350°F) environment solder, boards, etc. ✪✪✪✪✪✪✪✪✪ • Develop new elastomers • All “metal” motors ✪ • More efficient motors and MWD ✪✪ • Multizone hydrocarbon flow control ✪✪ • Equipment health monitoring and predictive maintenance ✪✪✪✪ • Logging tool robotic carrier in horizontal well • New type of batteries/power supply – long life in high temperature ✪✪✪✪✪✪ • High efficiency (low power consumption) electronics ✪✪	• Improved sensor specification more robust ✪✪ • Seismic while drilling sensors • Develop bit status and condition sensors ✪✪✪✪ • Downhole 4D seismic ✪ • Fiber optics sensors logging ✪✪✪✪✪ • Downhole seismic source ✪✪✪ • Real Time (RT) pore pressure ✪✪✪✪✪✪	• Deep core taking capability ✪✪ • Correlate formation to cores • Formation tester/sampler while drilling	• Active downhole vibration control ✪✪✪✪✪ • Downhole “closed-loop” systems ✪✪ • Short hop communications for bit data transfer • Models of rock comminution ✪ • Make tougher (stronger) bits ✪✪	• Standard data DH and SRF gathering (standards) ✪✪✪✪ • Data mining and fusion ✪✪ • Faster data transmission media (e.g., fiber optics) • Algorithms high speed/RT data analysis ✪✪ • Downhole diagnostics drilling parameters ✪✪✪✪✪✪✪✪✪✪ • Composite drill pipe or coiled tubing with data lines • Knowledge capture and sharing lessons learned ✪ • Genetic algorithm based drilling programs • RT well remote monitoring ✪✪✪	• New industry growth to influence change • Expose oil companies to new technologies • Risk sharing	• Tiny tools • Low cost disposable MWD tool • Reduction of flat time while drilling ✪ • Drilling using casing • ROP enhancement program ✪	• Algorithms real time display to increase learning rate ✪ • Increase multi-disciplinary groups • New super-deep modern drill rigs (like was done for DW) ✪

✪ = Vote for priority topic.

Drilling Diagnostics & Sensor Systems
What Actions to Take Advantage of R&D Opportunity?

OPPORTUNITY WITH DETAILS	ACTIONS PRODUCTS TOOLS	RESOURCES	LEAD ROLE COLLABORATION	TIME/$
PRIORITY #1 • Downhole diagnostics drilling parameters – Data validation – Weight torque on bit – State of BHA – Motor Δp, T, RPM – Bit cutting structure – Wear state – Temperature – Loading – Gas in wellbore – Equivalent circulating density – Interpretive algorithms – Straight hole?	• Industry performance baseline by basin • High accuracy directional drilling tool • Low cost retrievable tool • Disposable small diameter tool • Drilling reliability tool • System integration • Bit on bottom? • Standards for rig instrumentation and design • Better sensors for better understanding of rock properties • Prevent bit damage • Cutting structure – Condition? – Is hole being cleaned? – What kind of rock drilling?	• Industry training and drilling objectives • Better seismic while drilling • Coring while drilling • Better materials, e.g., diamond bearings • DH processors • Memory tool non-retrievable	• Service company via JIP • Ocean drilling program • Industry collaboration • Test facility • Lab, university consortia • Small business involvement • DOE - deep drilling data base	• Leveraging
PRIORITIES #2 and #3 • Electronic assemblies HT >350°F environment • New type battery/power supply-long life in high temperature – 225°C EE PROM – DSP – 225°C SMPS 90% efficiency	• Micro-machine sensors • High speed OP-AMP 10 MHz R to R single supply • Small scale refrigeration • Caps 100 µf 100 volt • FPGA 225°C	• Weapons programs • Academia research • National labs • Government/government foreign – United States	• Government/labs with defense industries • Existing industry via DOE/JIP	• Sustainability?
PRIORITY #4 • Real time pore pressure – What is real time? – Drill at balance continuously	• Seismic while drilling • Operating procedures to react to RT pore pressure • Volume of cuttings • Gas in well bore measurement tool • Mud density analysis • Automate kick detection and control • Delta flow measurement capability at surface	• DEA 119, 135(?) • Geoscience physics community	• Associations, universities	
PRIORITY #5 • Active Downhole Vibration Control – Measure and interpret – Bit whirl	• Closed loop • Procedures to get out of it • Initial detection signal recognition • Modeling of event "synchro" • Instrumentation of drill string • When to use turbines and/or PDM	• Aerospace industry • IFP (French) • Academia • Labs • Small Business	• DOE/DEA • Geothermal	

IV. DRILLING & COMPLETION FLUIDS

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Drilling & Completion Fluids

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Wayne Stewart	Drilling Specialties

**Report out presenter*

FACILITATOR: Brett Humble, Energetics

Drilling & Completion Fluids
What Are the Barriers?

GENERAL TOPICS
• Rheology (Hole cleaning, cuttings transport, gel strength @ temperature change) • Bean Counter's rules • Depleted formations • Gas solubility • Corrosion control in heavy brines (zinc based, greater than 400 degrees F) • Damage to production zone by fluid • Water based Mud (WBM) performance equal to Synthetic based Mud (SBM)/Oil based Mud (OBM) • Inadequate lab testing capability • Lubricity – torque and drag in deviated holes • Interdisciplinary communications problems • Rheological stability with temperature change • Formation damage (reverse circulation drilling, open hole from bottom up) • Cuttings transport (reverse circulation drilling) • Mud weight determination with gas cut – BHP • Time off bottom is high • Thermal stresses • Temperature stability of WBM at 300 degrees F and greater • Federal/State regulations • High pressure (greater than 18 lb/gal • Well bore stability (lost circulation) • Hard rock abrasion wear to bits • Ability to define environment – comp strength, shear strength, fracture, pore pressure, abrasivity. Geology

Drilling & Completion Fluids
What Are the R&D Opportunities to Overcome Barriers?

DISPOSAL/WASTE TREATMENT	FLUID DESIGN	FLUID TESTING/OPERATIONS
• Develop approved disposal method for material from well operations ✪✪✪✪✪	• Develop method of modeling to capture the mechanical/chemical interaction of rock/fluid ✪✪✪✪✪ • Develop WBM that mimic performance of OBM ✪✪✪✪ • Develop non-damaging completion fluid that has low fluid loss ✪✪✪ • Develop a quick way to measure fluid compatibility with formation ✪✪ • Mineral oil invert – salt saturated weighted mud with thermal stability ≥ 500 degrees F • Reversible WBM/Invert –Lubricity – ROP – Regs/Legs • Design of an economical ROP vs Fluid & Temp & Pressure Test Procedure • Develop method/procedure to determine formation composition from nuclear logs (chemistry, reactivity, type of mud) • Develop advanced synthetic muds – thermal-regs/legs-ROP • DF-Filtercakes that enhance cement bonds • Self-sealing DF systems (Removal of LCM from fractures)	• Develop economical tests & simulators for drill fluid contribution to well-bore stability ✪✪✪✪✪✪ • Real-time Rheology & Chemistry (surface first, down-hole later) ✪✪✪ • Under-balanced drilling – high volume degassing ✪✪ • Rheology as a function of time pressure & temperature • Develop a method for quickly testing cuttings

✪ = Vote for priority topic.

Drilling & Completion Fluids
What Actions to Take Advantage of R&D Opportunity?

#	PRODUCT/DELIVERABLE	ACTIONS	WHO DOES/LEADS	COLLABORATIONS	SCHEDULE/RESOURCES
1	Develop economical tests & simulators for drill fluid contribution to well-bore stability	• Define the problem • Develop fundamental understanding of mechanisms in order of priority • Define constraints • Develop test procedures & equipment	(no lead, only collaboration)	• Industry/Gov't & Universities	Multi-year > $1,000,000
2	Develop environmentally approved method for disposal of well operations materials	• Evaluate regulatory issues • Identify materials included in disposal • Propose alternate treatment methods • Test/demonstrate methods to gain regulatory acceptance	(no lead, only collaboration)	• DOE/National Labs assess legacy • Industry/Universities work with regulators to develop guidelines (include stakeholders, NGO's)	Multi-year > $1,000,000
3	Develop modeling to capture the mechanical/chemical interaction of rock/fluid	• Verify results from product # 1 • Model should be able to reproduce results from # 1 • Field validation of model	(no lead, only collaboration)	• Universities/Industry	2-3 years > $500,000
4	Develop WBM to serve as alternatives to SBM/OBM	• Define constraints • Determine who is doing what • Conduct lab testing to determine viability • Identify potential for field evaluation	Service companies/industry	• Chemical Industry/Universities	2-3 years Multi-million
5	Real-time rheology * & chemistry (surface first, down-hole later)	• Identify what properties of fluid you want to measure • Identify best sensors • Propose prototype measurement system • Test prototype	Oil & gas industry	• Utilize expertise from other industries/National Labs	Multi-year Multi-million

*Need to utilize circulation chips which can be placed in fluids and circulated to obtain measurements

V. Completion-Based Well Design Group Products

The general change to the group was to: "Discuss the interplay between the drilling and completion process, as well as the optimized design of casing and completion programs. Materials needed for high-temperature completions will be identified, along with high-temperature cement and cement placement techniques." Given this change, the group developed three products:

Participants
Completion-Based Well Design

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**Report out presenter*

FACILITATOR: Jim Carey, Energetics

- Barriers to cost-effective deep well systems,
- Technology opportunities to overcome these barriers, and
- Action plans for five priority R&D topics.

The group first brainstormed on the barriers to achieving cost-effective systems. The issues generated were then grouped into logical categories. Three major technical areas were identified: well integrity, data acquisition and quality, and drilling processes and equipment. In addition, three non-technical areas were identified: regulatory issues, the availability of technical expertise, and technology risk. The complete results are shown in Table 1.

Based on these barriers, the group brainstormed on technology opportunities. The topics identified were then grouped into six general topic areas: simulation, materials and fabrication, tools and techniques, sensors and data management, human resources and expertise, and risk management. The group then voted on priority topics and the complete results are shown in Table 2.

After voting, the top vote-getting topics were aggregated into a set of five priority topics for which action plans would be prepared. A sixth topic, risk analysis and risk sharing, was deemed a critical cross cutting issue for the other five.

The five topics were as follows:

- Develop and apply high-temperature, high-pressure sensors and information tools to drilling and completion processes.

- Accelerate development of tubular solutions.

- Develop downhole solutions to surface production problems.

- Optimize longevity of wellbore through numerical analysis of wellbore and completion systems.
- Develop (cheap) enhanced sealants and placement techniques.

For each topic, the group identified products/deliverables, resources (knowledge and expertise), who leads/collaborates, schedule, and dollars. Table 3 presents the complete results for the action plans.

In addition to the products shown in the tables, there were a number of general issues and crosscutting topics that were repeatedly noted during discussions.

- It is critical to view completions as an integrated part of well planning and design in order to assure productivity over the *entire* well life cycle.
- There is general industry tendency to focus more on the short-term benefits in reducing the up-front costs of drilling as opposed to maximizing the longer-term payoff of longer well life and greater total production from improved completion tools and techniques.
- In a generally risk-averse environment, it is difficult to promote the use of new technology in field operations. The cost of failure is generally seen as prohibitive, particularly in very costly deep wells. For example, there are existing new tools/ techniques that have been developed but not yet applied.
- There is growing concern over the continued availability of the necessary technical expertise to apply advanced technology. What may be termed the "expertise pipeline" for new talent, as measured by college and university programs and the flow of students, continues to shrink. For example, in one of the companies represented in the group, only 9% of the technical workforce are less than 30 years of age.
- There is the need to consider "blue-sky" technology options that could provide revolutionary approaches to completion tools and techniques. Part of developing these options would be to examine and adapt developments (e.g., in electronics and information technology) from outside the oil and gas industries.
- Bringing in technical expertise from outside the "typical" oil/gas world capabilities (e.g., reservoir engineering, geotechnical) can both facilitate the use of new technology and prevent "reinventing the wheel."
- Perhaps most importantly, in any technology development there is the absolute necessity for technology developers to understand the real-time needs and problems of field operations and personnel. This particularly true for any "blue-sky" efforts to be successful.

Tables 1 through 3 follow.

- Table 1. Barriers
- Table 2. Opportunities
- Table 3. Action Plans

Completion-Based Well Design
Table 1. What Are the Barriers to Cost-Effective Deep Well Systems?

WELL INTEGRITY	DATA ACQUISITION/QUALITY	DRILLING PROCESS/ EQUIPMENT	TECHNOLOGY RISK	TECHNOLOGY EXPERTISE	REGULATORY
• Cement durability: cyclic pressure and temperature stress failure • Well integrity during and after drilling – Bore hole stability – tensile and compressive failure – Crossflows – Casing damage – Leaking annular gas: *short*- and *long*-term • Corrosive environment (high-cost tubing) • Thermal stability of cements • Compaction-induced failures: – How to assess – Mapping – Mechanisms – Completion methods • Equipment production durability – Hard rock, – High temperature, – High pressure, – Corrosives • Limitations in stimulation processes/ procedures • Flow assurance	• Handling/analysis of large amounts of data • Understanding of down hole conditions in real time • Accurate temperature prediction (geothermal cementing) • Data-cost component of project • LOT/FIT procedures and interpretation • Insufficient data – Well testing – Production data • Is there truly a reservoir grade petroleum system down there?	• Float equipment for reverse circulation cementing • Rig design to achieve faster trips reeled pipe for example • Cement placement: – Challenging well conditions limit cement placement with conventional methods – Possible solution: reverse cementing • Productive time on bottom versus non-productive time • Long-term well reliability vs. up-front drilling $ • High-temperature electronic components (lack of) • When you get there do you end up with a "usable" hole size? • Lost circulation – Mud losses – Well control – Too many casing strings • Additives – Cement and fluids • Borehole optimized for production not just ROP • 1:1 drilling/completion cost ratio	• Absolute necessity needed for innovation • Lack of $ for high-risk efforts • Knowledge of existing technology by operators • State-of-the-art not brought to state-of-use practice • Access to existing high-dollar technologies • Contractor-customer interface can restrict advances in technology • Conservative decision makers in drilling role, culture • High well cost limits testing opportunities • Difficult to prove how more up-front cost can prevent long-term problems, i.e., slow degradation of zone isolation causing loss of hydrocarbons to other zones • Zero tolerance for error • Data quality needs	• Lack of technology development personnel expertise • Lack of folks for the future: education/training pipeline	• Waste handling • Use of synthetic materials • Produced fluids • Risk-based decision analysis is lacking • Annular gas regulation (gas migration)

Completion-Based Well Design
Table 2. What Are the Technology Opportunities to Overcome the Barriers?

SIMULATION	MATERIALS AND FABRICATION	TOOLS AND TECHNIQUES	SENSORS AND DATA MANAGEMENT	RISK MANAGEMENT (CROSSCUTTING TOPIC)	HUMAN RESOURCES AND EXPERTISE (CROSSCUTTING TOPIC)
• Wellbore stability optimization using wellbore numerical models ✪✪ • FEA (finite element analysis) of well integrity over production life ✪✪ • Coupled modeling of P, T, chemical stress effects on wellbore materials • Develop well/cat integrity models for casing stress and failure • Optimization of well design for production through simulation	• Membrane technology downhole to eliminate corrosives ✪✪ • Downhole separation/ injection ✪✪ • Expandable metal/resilient/metal liner hangers ✪✪ • Develop and apply non-metal tubulars for corrosive HT environment ✪✪ • Composite materials ✪ • Better manufacturing processes—tubulars • Develop insulated (temperature) drill pipe	• Develop technology to increase borehole pressure integrity ✪✪ • Develop reverse circulation tools ✪ • Ductile cements to resist HT/HP ✪ • Reverse cementing ✪ • Annular seal design—“cementless’ wells • Develop and validate BHCT models ✪ • Underbalanced drilling: HT/HP and deep water • Jet/impact drilling—no Bit/no trip • Bit replacement without tripping • Cost efficient, operations-friendly reservoir tests for improved data • High-temperature components for MWD/LWD • Computer-assisted drilling operations • Cheap deep water well test systems • Bi-center bit and expandables	• Data collection ahead of drill bit ✪ • Integrated and robust sensor and telecommunications (e.g., fiber optic in composite tubing casing) ✪ • High-temperature smart completions (sensors, actuators) ✪✪ • Well database analysis to find and prove key factors (root cause and causal effects) ✪ • Integrated data and information systems (data mining) ✪✪ • Leak-off flow path characteristics analysis and measurement • Real time 3-D imaging of hole while drilling	• Dollars to reduce risk of lost investment in developing new technology for domestic drilling problems: Deep, high temperature, high pressure, etc. • Risk based safety/ environmental analysis ✪ • Subsidize technology testing risk ✪✪✪ • Provide *large* tax incentives for providing break-through technology solutions to industry • Level out swings in price, people equipment cost • Relating value of data analysis techniques (management/technical interface) • Lease new acreage with tie to development plan and data acquisition plan, not just money	• Potential solutions in Russian technology • API and government joint development of Best Practices • Web-based training • Research programs for U.S. graduate students

✪ = Vote for priority topic.

Completion-Based Well Design
Table 3. Action Plans for Priority Topics

Topic	Products/ Deliverables	Resources (Knowledge and Expertise)	Who Leads/ Collaboration	Schedule	Dollars
Develop and apply high-temperature/high-pressure sensors and information tools to drilling and completion processes (7 votes)	• Field test: – Sensors – Data delivery systems – Data collection and analysis systems – Show reliable data streams over time • E.g., make current MWD more robust • E.g., permanent sensors in wellbore for well / completion stability/ longevity • E.g., data management (data mining)	• Expertise in – HT/HP electronics – Micro devices – Data transmission (optical and others) – Information technology – Field experience is critical • Do not limit to current industry knowledge	• Neutral but inclusive; JIP, national lab consortium – Include service companies – Must be clear path to commercialization – Pay attention to "Hand-off" to commercialization/ service companies	• 5 years	• Not cheap • Cost-sharing • Balanced funding across critical pieces
Accelerate development of tubulars solutions (corrosive, DEEP, HT, HP) (5 votes)	• Temperature-resistant composite tubulars (T, P, stress) • Expandable systems (e.g., monobores, cementless systems, self-sealing systems) • Embedded sensors/ data conduits	• Materials science – Metallurgy – Composites – Sensors – Microdevices • Draw from outside – Learning curve is moving	• JIPs – Multiple with more than oil/gas industry – "Blue-Sky" component with national labs	• Staged commercial products (e.g., some things are already in development)	• $50 million over 5 years
Develop downhole solutions to surface production problems (4 votes)	• Develop reliable downhole HT separators (for water, gas, corrosives as well as for asphaltenes, hydrates, etc.) • Develop formation injection systems • Smart systems for monitoring and control	• Electronics • Processing sciences • Chemical engineering • Geomechanics • Reservoir engineering	• State-of-the-art is trash; thus national lab led effort (with industry, university, service companies) • Lab for fundamentals, then → JIP, service company lead	• Transfer of first results (lab → JIP, service companies) in 3 years – But do not rush it	• $10 million over 5 years
Optimize longevity of wellbore through numerical analysis of wellbore and completion systems (4 votes)	• Develop and *validate* • Numerical analysis tool: modules for existing backbones • Expert systems for real-time decision support of drilling and completions – Modules to fit with existing systems (backbones) – Open access – User-friendly – Data-friendly	• Import expertise in information technology • Earth sciences • Combine with the real field users – Couple strong math background with field reality – Coordinate/integrate with existing backbone folks	• Over-arching JIP – Know current backbones – Spec modules • Small JIP per module • Coordinate with GRI activity	• 2 years: validation and gap analysis of existing systems • Staged incorporation of new modules • Demonstrate enhanced real-time expert system at 5 years	• Validation: $2 million over 2 years • Total program: $50 million?

Completion-Based Well Design

Table 3. Action Plans for Priority Topics *(continued)*

Topic	Products/ Deliverables	Resources (Knowledge and Expertise)	Who Leads/ Collaboration	Schedule	Dollars
Develop (cheap) enhanced sealants and placement techniques (3 votes)	• Develop and field demonstrate – Ductile cements – Non-Portland cements – Non-cement alternatives • Integrate new approaches into models	• Structural engineering • Metallurgy • Completion engineering • Materials science • Rheology	• JIP for cement applications • Industry (outside)/lab/ university consortium for non-cement "Blue Sky"	• HT/HP cement: – Field trial in <2 years • Consortium: – Concepts in 2 years – Then industry review – Field tests in 5 years	• HT/HP cement demos – ~$1 million per on low end – ~$10 million total • Consortium: – ~$5 million for first 2 years – ~$10 million for field tests

Deep Trek Workshop

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